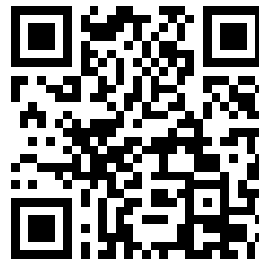


---

This is a reproduction of a library book that was digitized by Google as part of an ongoing effort to preserve the information in books and make it universally accessible.

Google<sup>TM</sup> books

<https://books.google.com>



Y 3. At7

221 SRIA-3

AEC

RESEARCH REPORTS

SRIA-3

HEALTH AND SAFETY

# FALLOUT CONTROL

Final Report

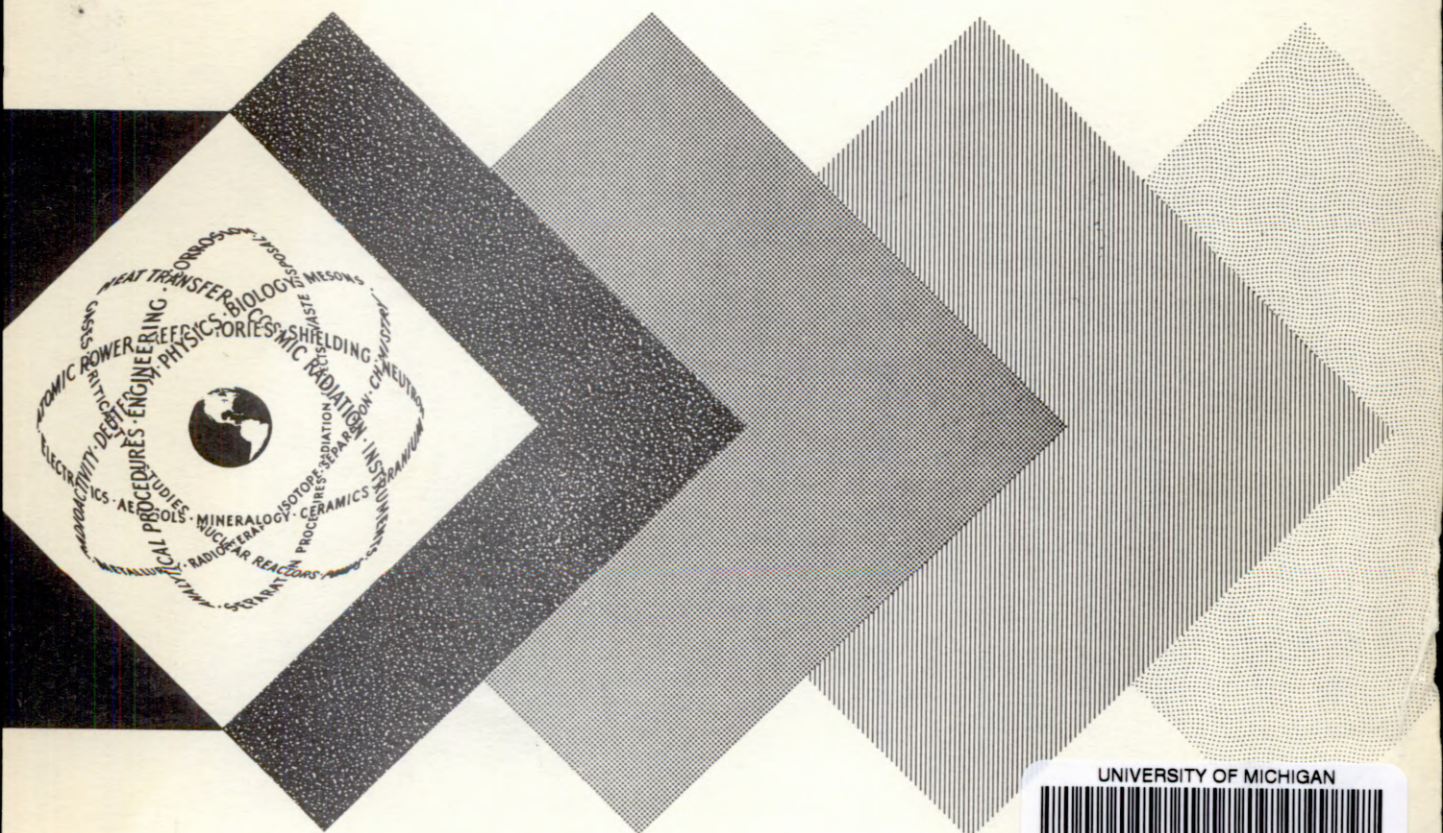
By

C. E. Lapple

UNIVERSITY OF  
ARIZONA LIBRARY  
Documents Collection

JUN 3 1959  
August 1, 1958

Stanford Research Institute  
Menlo Park, California



UNIVERSITY OF MICHIGAN



3 9015 09504 1797

UNITED STATES ATOMIC ENERGY COMMISSION

Technical Information Service

Digitized by Google

## LEGAL NOTICE

This report was prepared as an account of Government sponsored work. Neither the United States, nor the Commission, nor any person acting on behalf of the Commission:

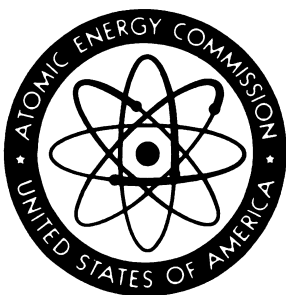
A. Makes any warranty or representation, expressed or implied, with respect to the accuracy, completeness, or usefulness of the information contained in this report, or that the use of any information, apparatus, method, or process disclosed in this report may not infringe privately owned rights; or

B. Assumes any liabilities with respect to the use of, or for damages resulting from the use of any information, apparatus, method, or process disclosed in this report.

As used in the above, "person acting on behalf of the Commission" includes any employee or contractor of the Commission, or employee of such contractor, to the extent that such employee or contractor of the Commission, or employee of such contractor prepares, disseminates, or provides access to, any information pursuant to his employment or contract with the Commission, or his employment with such contractor.

This report has been reproduced directly from the best available copy.

Printed in USA. Price \$3.50. Available from the Office of Technical Services, Department of Commerce, Washington 25, D. C.



*August 1, 1958*

*Final Report*

**FALLOUT CONTROL**

*By: C. E. Lapple*

*SRI Project No. SU-2479*


*Prepared for:*

U. S. ATOMIC ENERGY COMMISSION    SAN FRANCISCO OPERATIONS    OAKLAND, CALIFORNIA

*Project Agreement No. 5  
under Contract No. AT(04-3)-115*

*Approved:*

  
-----  
O. F. SENN, CHAIRMAN    DEPARTMENT OF CHEMISTRY

  
-----  
DONALD L. BENEDICT, DIRECTOR    PHYSICAL SCIENCES RESEARCH



## CONTENTS

---

I	INTRODUCTION . . . . .	1
II	OBJECTIVE . . . . .	3
III	GENERAL PHILOSOPHY AND METHOD OF APPROACH . . . . .	3
IV	SUMMARY AND CONCLUSIONS . . . . .	4
V	PROGRAM FOR FURTHER WORK . . . . .	7
VI	BASIC DATA . . . . .	8
A.	Fireball and Cloud . . . . .	8
1.	Radioactive Decay Relationships . . . . .	8
2.	History of Fireball and Cloud . . . . .	9
a.	Fireball Surface Temperature and Size . . . . .	10
b.	Rise of Fireball and Cloud . . . . .	11
c.	Growth and Cooling of Fireball . . . . .	12
d.	General Discussion . . . . .	14
3.	Fireball and Cloud Debris . . . . .	16
4.	Vapor Pressure and Melting Point Data . . . . .	17
5.	Particulate Formation . . . . .	18
B.	Fallout . . . . .	22
1.	Type and Nature of Fallout . . . . .	22
2.	Mechanisms and Rate of Fallout . . . . .	23
3.	Strontium-90 in the Atmosphere . . . . .	26
C.	Strontium-90 Entry into Food . . . . .	27
D.	Summary . . . . .	29
VII	DISCUSSION OF POSSIBLE CONTROL MEASURES . . . . .	31
A.	Measures Involving Physical Characteristics . . . . .	31
1.	Increase Storage Time . . . . .	31
2.	Increase Local Fallout . . . . .	32
3.	Alter Fallout Distribution . . . . .	35
B.	Measures Involving Physico-Chemical Characteristics . . . . .	38
1.	Change of Phase . . . . .	38
2.	Change of Solubility or Reactivity . . . . .	38
a.	Change of Compound . . . . .	39
(1)	Inorganic . . . . .	39
(2)	Organic . . . . .	40
b.	Embedding . . . . .	41

## CONTENTS

c. Coating . . . . .	43
(1) Inorganic . . . . .	44
(2) Organic . . . . .	45
C. General Considerations . . . . .	46
NOMENCLATURE . . . . .	49
ACKNOWLEDGMENT . . . . .	53
FIGURES . . . . .	55
TABLES . . . . .	67
APPENDIX A    TERMINAL SETTLING VELOCITIES AND DIFFUSION COEFFICIENTS FOR AEROSOL PARTICLES . . . . .	A-1
APPENDIX B    VAPOR PRESSURE AND MELTING POINTS . . . . .	B-1
APPENDIX C    FISSION PRODUCT DECAY RELATIONSHIPS . . . . .	C-1
APPENDIX D    DIFFUSIONAL GROWTH AND DEPOSITION OF PARTICLES . . . . .	D-1
APPENDIX E    PARTICLE SCAVENGING . . . . .	E-1
APPENDIX F    BIBLIOGRAPHY . . . . .	F-1

# FALLOUT CONTROL

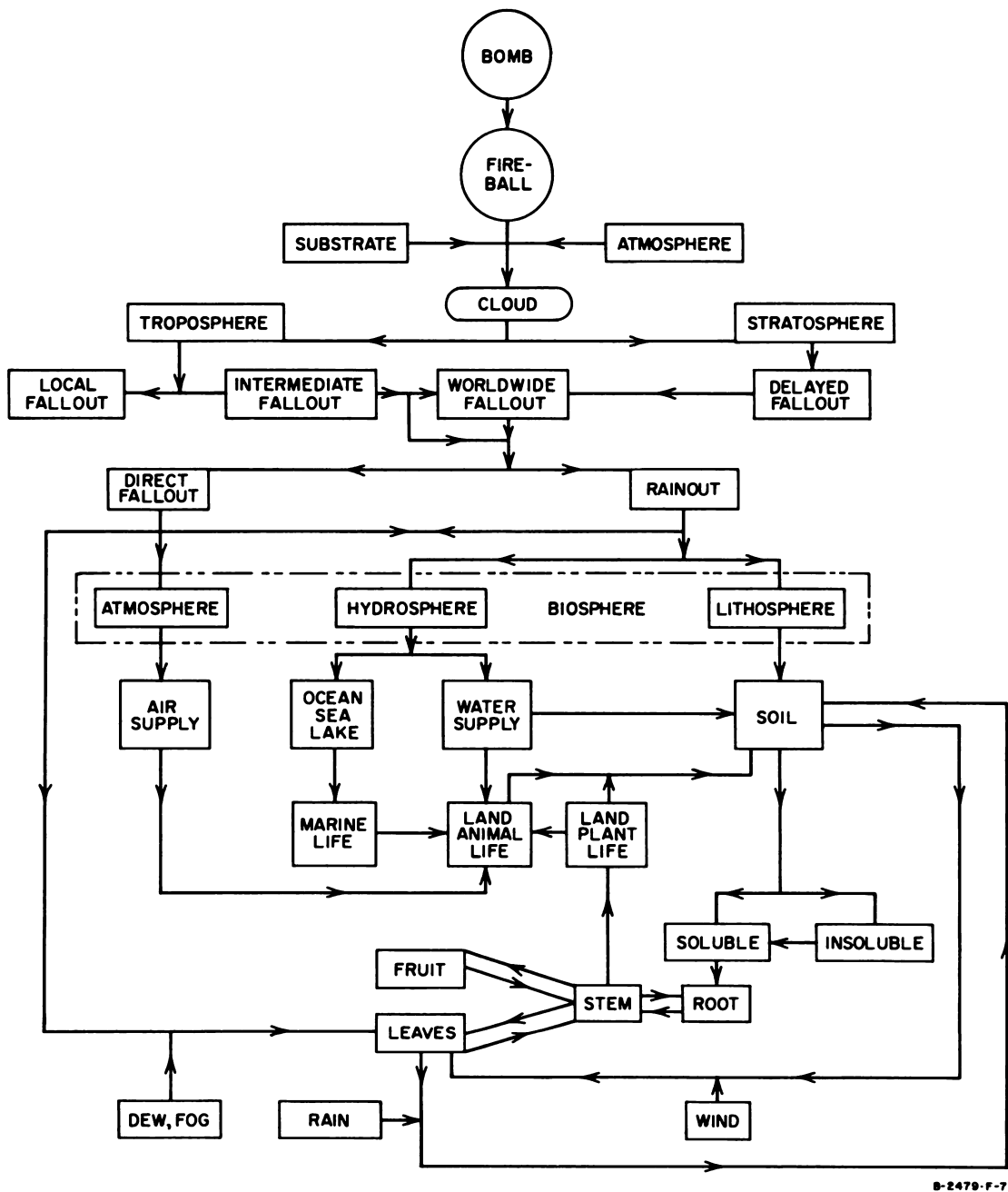
## I INTRODUCTION

Following the explosion of a nuclear weapon, a great deal of radioactive material, primarily fission products from the weapon, is introduced into the atmosphere. This material falls or is carried to earth at various times and distances from the time and point of the explosion, much of it being distributed over the entire earth. Some of the radioactive fallout has a relatively short life; although its intense radiation constitutes the primary hazard at sites close to the point of detonation, it soon decays. It is the widely distributed, long-lived fallout that constitutes weapons testing's primary somatic hazard to man, because it can be assimilated by vegetation, animals, and humans over vast areas and over long periods of time. The direct human intake of radioactive materials from drinking water, from air, and through the skin is small compared with the indirect intake through foods such as fruits, vegetables, milk, and meat. The ability of at least some forms of vegetation and organisms to concentrate specific elements accounts for the predominant role of vegetation as the major source of human intake of radioactive materials. Figure 1 gives a flow sheet of the various paths of fallout material from the time of its inception in the bomb to its ultimate ingestion by land animal life (including man).

Of the various fission products, strontium-90 and cesium-137 are considered to be the most hazardous because of their long lives and relatively high emission rates. Of these, strontium-90 is considered the most dangerous. Because of its similarity to calcium, it tends to concentrate in the bone structure rather than being excreted quickly, and hence has a relatively long biological life. For most populations the bulk of the strontium-90 enters man through milk and dairy products, which in turn reflect the transfer of strontium-90 from vegetation to cow.

Most investigations of fallout to date have been directed at evaluating the nature and extent of the hazard. There has also been an





B-2479-F-7

FIG. 1  
ORIGIN, TYPES, AND DESTINY OF RADIOACTIVE FALLOUT

intensive effort directed toward minimization of the hazard by appropriate design of the nuclear reaction in the weapon to minimize formation of the objectionable fission products. The present study is aimed at development of control measures that can be applied to the fireball or cloud for the purpose of reducing or eliminating the ingestive effectiveness of fission products (with particular emphasis on strontium-90) that result from a nuclear detonation.

## II OBJECTIVE

The purposes of the present study are: (1) to assess the feasibility of various conceivable fallout control measures applied to the fireball or cloud in the light of known information and knowledge, and (2) to indicate a program for experimentally developing additional information necessary for assessment of these control measures. This study is concerned with long-range effects of weapons testing only, not with nuclear warfare or nuclear accidents.

## III GENERAL PHILOSOPHY AND METHOD OF APPROACH

Since it is generally agreed that the major long-range somatic hazards of nuclear weapons testing arise from the formation of strontium-90 and its concentration in or on vegetation, this study emphasizes strontium-90 on the philosophy that any control measures must be capable of dealing with it. If strontium-90 cannot be successfully dealt with, there is little to be gained in controlling other fission products; if it can be controlled successfully, consideration of control measures for other fission products can then be justified.

The project was also governed by the philosophy that any control measures should achieve an order-of-magnitude reduction in hazard—not simply a minor improvement.

The following is a summary of the various conceivable general approaches through which control might be achieved. This summary provides an insight into the nature of considerations and areas of knowledge that may be involved in any detailed evaluation of the specific methods of control to be discussed later.

- A. Preventing the formation of strontium-90: this involves the design of the nuclear reaction and is specifically excluded from consideration in this study.

- B. Altering the characteristics of strontium-90 to reduce its ultimate hazard effectiveness by
  - 1. Storing the strontium-90 in the atmosphere for sufficiently long times to permit decay of activity
  - 2. Reducing the rate of deposition of strontium-90 in critical areas, or, as a corollary, increasing the rate of deposition in noncritical areas, by
    - a. Increasing the close-in, or local, fallout
    - b. Changing the distribution of long-range fallout between vegetation and soil
  - 3. Reducing the effectiveness of uptake of strontium-90 by vegetation through
    - a. Appropriate control of the physico-chemical properties of the fallout material in the fireball or cloud
    - b. Palliative measures applied to the soil: this alternative is specifically excluded from consideration in this project

In order to provide a basis for evaluation, the available information in the areas of interest bearing on this problem was ascertained through a search and review of both the classified and the unclassified literature. Appendix F gives a summary of the references compiled, categorized, in the case of the unclassified references, according to the several areas of interest indicated. Details as to the abstract sources consulted are also given. It was ultimately concluded that the large bulk of the knowledge pertinent to this problem is summarized in three unclassified reference sources.<sup>18,47,73</sup> The current status is summarized by two other unclassified references.<sup>37,72</sup>

#### IV SUMMARY AND CONCLUSIONS

Table I gives a summary of the various conceivable control measures that might be applied, together with a summary of the principal factors governing the feasibility of each. Additional research required to obtain definitive data is outlined in the next section. So far, the following general conclusions have been drawn.

##### A. Control Measures Based on Particle Size

- 1. Mechanical scavenging of the fireball cloud by large particulates of controlled size (about 100  $\mu$ ) to achieve increased local fallout of fission products

Table I  
SUMMARY OF TYPES AND LIMITATIONS OF CONCEIVABLE CONTROL METHODS

GENERAL TYPE OF CONTROL METHOD	SPECIFIC PURPOSE OF METHOD		COMMENTS AND LIMITATIONS
A. Involving a change of physical characteristics (principally effective particle size)	1. To achieve increased stratospheric storage time (storage for several hundred years necessary)		Not possible because: (1) Storage is believed to be controlled by air interchange rates between stratosphere and troposphere and not by particle settling velocity (2) If particle settling velocity were controlling, it would have to be reduced to some 100 ft/yr, corresponding to <0.03-micron particles. Such particles would be effectively scavenged either immediately by the fine debris from a surface burst in the fireball cloud or by the stratospheric dust in a period of less than 10 years
	2. To increase local fallout	a. By growth of strontium-90-bearing particles in fireball cloud	Not possible because there is insufficient time to grow particles large enough (>100- $\mu$ diameter)
		b. By condensation of $Sr^{90}$ on large debris particles (>100 $\mu$ )	Possible but of limited effectiveness: (1) Limited to surface bursts (2) Large amounts will also condense on fine debris (<100 $\mu$ ), which must be mechanically scavenged by large debris particles
		c. By mechanical scavenging (deposition of $Sr^{90}$ -bearing particles on large debris particles)	Possible: (1) Limited to surface bursts (2) Scavenging effectiveness can be increased by increasing the amount and controlling the particle size of substrate in the vicinity of 100 $\mu$ . Rough estimates indicate scavenging requirements of some 600,000 tons/MT for 100- $\mu$ -diameter scavenging particles, but bases for estimation are not well established (3) Requires substrate control either by site selection or by substrate preparation
	3. To alter fallout distribution between soil and vegetation		No significant control possible because: (1) Ultimate total worldwide deposition rate cannot be changed since it is determined by weapons testing rate alone (2) Primary mode of plant entry will be through soil, for which deposition rate cannot be changed appreciably (3) Distribution by rainout cannot be changed except momentarily (4) Dry fallout rate could conceivably be reduced by particle size control in range <0.1 $\mu$ . Such particles, however, would not be stable in the atmosphere for a sufficiently long time. (Their effective size would be determined by atmospheric dust.)
B. Involving a change in physico-chemical characteristics	1. To change phase		No known possibility and of dubious utility. (1) $Sr^{90}$ will exist in solid phase in the atmosphere (2) No inorganic compounds known by which phase can be changed to gaseous, which requires vapor pressure of more than $10^{-10}$ mm Hg.
	2. To reduce solubility or reactivity	a. By change of compound	(1) Inorganic Possible but of questionable feasibility (1) The boride is the only known compound of Sr with possible adequate insolubility (2) The boride requires a reducing atmosphere for formation. This may require addition of some $10^6$ tons of carbonaceous matter/MT to substrate (3) Long term stability of $SrB_2$ in soil and air is questionable, especially if particle size is small
			(2) Organic Possible but of questionable feasibility (1) Restricted to air bursts for economic reasons (2) Sr dye lakes may be sufficiently insoluble, although long-term stability in soil and air is questionable because of small particle size (3) Requires external addition to fireball cloud (4) Possible continuous addition to stratosphere not feasible economically
		b. By embedding in insoluble matrix	Possible (1) Requires that temperature be sufficiently high at time most of $Kr^{90}$ has decayed so that matrix material will be above melting point. This probably restricts applicability to shots larger than 10 MT unless addition of carbonaceous substrate is considered. (2) In the case of air bursts, the long-term stability of matrix material is questionable because of small particle size
		c. By coating	Possible but questionable (1) Limited to air bursts or, possibly, bursts over deep water for economic reasons (2) Long-term stability of coating agent is questionable because of small particle size and thin coating (3) Inorganic coating agents probably limited to bursts larger than 10 MT because of time-temperature history (4) Organic coatings probably restricted to plastics having suitable vapor pressure characteristics, because of economic considerations

is the only feasible means for utilizing particle size as a control measure.

2. Particle size control of the *bomb debris* in the fireball cloud does not offer any promise for controlling the ingestive hazard of long-range fallout because
  - a. The ultimate destiny of such fallout is not strongly dependent on particle size
  - b. The ultimate effective particle size is probably determined more by the size of atmospheric dust than by the initial size in the fireball cloud.

#### B. Control Measures Based on Chemical Addition or Modification

1. A serious limitation on fallout control by chemical means is the fact that, for shots smaller than 10 MT, fireball temperatures drop below reaction or fusion temperatures before most of the inert gas precursor, krypton-90, has decayed to strontium-90. The only contradiction to this limitation is the possibility of a concentrated core of hot, fission-product-laden gas within the fireball. Estimates indicate, however, that such a core could not be mechanically stable for the period of time necessary.
2. The possibility of forming insoluble compounds of strontium-90 (other than as related to embedding the strontium-90 particles in a matrix) is poor. The boride is the only known insoluble compound. The boride involves questionable features both as to means of formation and as to long-term stability.

#### C. Control Measure Application

1. The utility of additions to the bomb for purposes of fallout hazard control will probably be limited to air bursts (or possibly bursts over deep water); surface bursts will require control of the substrate characteristics.
2. For *air bursts*, potentially feasible methods of fallout hazard control are limited to coating the fission products with, or embedding them in, an insoluble matrix, or to forming insoluble organic compounds. The potentials for controlling air bursts are poor for either or both of two reasons
  - a. The questionable insolubility of protective materials over long periods of time with regard to fine particulates
  - b. The questionable feasibility of having a sufficiently high temperature with shots smaller than

10 MT at late enough times for the critical fission products to be in a controllable form.

3. For *surface bursts*, control of fallout through the medium of the substrate offers promise both from the standpoint of mechanical scavenging and from the standpoint of embedding fission products in an insoluble matrix. Substrate control can be achieved by site selection and/or by site preparation. The following are desirable substrate characteristics:
  - a. Particle size of the order of 100 microns, for effective mechanical scavenging
  - b. Large quantities of potential matrix material (such as silicates)
  - c. Large quantities of carbonaceous matter, for lengthening the time of the temperature cycle
  - d. Large quantities of fluxing agents (such as borates), to reduce the melting points of the matrix materials.

Without the addition of carbonaceous matter, the outlook for control by embedding in a matrix is poor for shots smaller than 10 MT for the same reason indicated above for air bursts.

## V PROGRAM FOR FURTHER WORK

The following summarizes key areas in which further research is required in order to provide bases for fully resolving the feasibility of various conceivable approaches to fallout control.

- A. *Mechanical Scavenging*: Further basic knowledge is needed to permit quantitative evaluation of the effectiveness of scavenging processes, especially in the matter of retention of previously scavenged particles.
- B. *Long-term Stability of Fine Particulates*: A number of conceivable control measures depend on embedding the fission products in insoluble or nonreactive compounds, coating the fission products with such compounds, or converting the fission products into such compounds. When present as fine particulates, normally insoluble or nonreactive materials may show appreciable solubility or reactivity because of the extensive surface available. To evaluate the seriousness of this potential limitation, data are required for specific systems, covering the range of conditions encountered in the atmosphere and in the soil. These systems include borides, dye lakes, silica or silicates of various types, and salts with thin coatings of silver, plastics, etc.

- C. *Vapor Pressure Over Mixed Phases:* In evaluating the feasibility of embedding fission products in a matrix by solution from the vapor phase, data are required on the vapor pressure of fission products (such as rubidium and strontium) over a variety of possible matrix materials, such as silicates, oxides, and borates.
- D. *Fireball and Cloud Temperature:* A serious restriction on the feasibility of fission product control by chemical means is the question of fireball temperature in relation to the decay rates. A more quantitative assessment of this limitation requires more detailed knowledge of the temperature distribution in the fireball and cloud as a function of time. Most previous studies have been concerned with times up to or just beyond the second maximum surface temperature. In control measure evaluations, only the temperature history in the time period 10 to 1000 seconds is of interest. Detailed evaluations of existing moving picture films and radiochemical studies of gross fallout material may reveal further useful details as to this temperature history. A detailed theoretical evaluation of the mechanism of fireball growth would also be desirable to provide a firmer basis for conclusions regarding fireball temperature and uniformity than is possible from the high-spot estimates that have been made in this study.

The above are required to establish technical feasibility. Once that feasibility is established, various other investigations would be required, although these would deal largely with details of methods for practical realization of specific control measures.

## VI BASIC DATA

In order to assess the potentials of specific control measures, we must know: (1) the conditions that exist and the mechanisms of fallout-particle formation in the fireball and subsequent cloud, (2) the distribution of fallout-particles in the world's atmosphere and their ultimate deposition, and (3) the mechanisms by which fallout material enters vegetation. The following summarizes the pertinent knowledge in these areas.

### A. FIREBALL AND CLOUD

#### 1. RADIOACTIVE DECAY RELATIONSHIPS

The fission of uranium-235 and plutonium-239, the two materials in common use in weapons today, results in a wide variety of radioactive materials. The fission yields from both of these materials are very

similar and subsequent discussions will refer to the fission of uranium-235, since most of the interpretative information in the literature has been given for uranium-235. Of the fission products, only strontium-90, and to a lesser extent cesium-137, are of direct concern in this project. Neither material is found to any significant extent as a primary fission product. Both are the product of decay of one or more precursors.

Appendix C gives a detailed evaluation of the decay history of the Mass-89, -90, and -137 chains. The Mass-89 chain has been included here because of the extensive data given for strontium-89 in fallout, as contrasted to relatively meager data for strontium-90. Strontium-89 and strontium-90 have as their immediate precursors rubidium-89 and rubidium-90, respectively. Except for a few very short-lived nuclides, the only other precursor is the inert gas, krypton. Similarly, cesium-137 has only the inert gas, xenon, as a precursor, except for relatively short-lived nuclides. Since there are no known methods for controlling inert gases, any control must be concerned either directly with strontium-90 and cesium-137 or with a chemically reactive precursor such as rubidium-90. The following data, from Appendix C, give a summary of times after fission at which various percentages of total strontium-89, strontium-90, and cesium-137 are in a controllable form:

CONTROLLABLE NUCLIDE	APPROXIMATE TIME AFTER FISSION, IN SECONDS, AT WHICH INDICATED NUCLIDE HAS FORMED TO THE EXTENT OF		
	50%	90%	99%
Sr <sup>89</sup>	1,200	3,300	10,000
Sr <sup>89</sup> + Rb <sup>89</sup>	200	600	1,500
Sr <sup>90</sup>	200	600	1,500
Sr <sup>90</sup> + Rb <sup>90</sup>	30	100	250
Cs <sup>137</sup>	250	800	2,000

It is apparent from the above tabulation that effective control (>90%) of strontium-90 and cesium-137 can be achieved only by action applied at times later than 100 seconds and 800 seconds after fission, respectively. Any earlier action would achieve relatively ineffective control.

## 2. HISTORY OF FIREBALL AND CLOUD

From the standpoint of condensation of particulate matter, the important period is the one after the fireball temperature has dropped



below some 3000°K, since, as will be shown below, all the material will be in the gaseous phase at higher temperatures. As shown above, it is also the time period 100 seconds after fission and later that is of greatest concern.

*a. Fireball Surface Temperature and Size:* Figure 2 gives the surface temperature history of the fireball for times later than one second after fission for various weapon yields. This figure was prepared from data presented by Glasstone<sup>18</sup> and the Rand Corporation<sup>47</sup> for a 20-KT yield, scaling time according to the square root of yield. This method of scaling has been shown to apply to the second maximum temperature<sup>18(p.331)</sup> and has arbitrarily been used as a basis for scaling the entire temperature history.

Other data for megaton and larger shots agree reasonably well with the values shown in Figure 2. However, there apparently has been no attempt to obtain good measurements below 2000°K. Past interest has been primarily in early fireball history and there are many technical problems involved in measurements below 2000°K. There is also considerable question as to the significance of an average surface temperature at these lower levels. It should be noted that there is approximately a two-fold difference in time corresponding to a given temperature between the data reported by Glasstone and those reported by The Rand Corporation.

The fireball attains its maximum size shortly after the second maximum temperature is reached.<sup>18(p.65),47(p.12)</sup> Table II lists the maximum fireball size for various weapon yields as reported by Glasstone.<sup>18(p.66)</sup> Although there is some variation with weapon size, the nominal magnitude of maximum fireball area and volume may be taken as 1 sq mi/MT and 1 cu mi/MT, respectively. For the purpose of future discussions, the use of such nominal values will be adequate, especially considering the fact that there is a two-fold spread in available data for maximum fireball diameters.

Glasstone<sup>18(p.20)</sup> reports that, for a 1-MT air burst, the maximum fireball diameter of 7200 ft is reached in 10 seconds, at which time the fireball is rising at the rate of 250 to 350 ft/sec. After 1 minute, the ball of fire has cooled to such an extent that it is no longer visible and has risen to a height of 24,000 ft above the point of burst.

b. *Rise of Fireball and Cloud:* Figure 3 gives the height of the fireball and cloud as a function of time for a 1-MT air burst, based on the average of data reported by Glasstone<sup>18(pp.36-40)</sup> and Graves<sup>73(p.55)</sup>, which agree reasonably well. The corresponding curves for 20-KT and 50-MT shots have been estimated by scaling both height and time by the cube root of yield<sup>18(p.104)</sup>. These curves may be taken as indicative of the rate of rise for intermediate time periods. In any specific burst, the actual height at early times will be determined by the burst elevation; the height at late times will be determined by the prevailing meteorological conditions in the tropopause and stratosphere.

As the fireball rises, one mechanism by which it cools is that of expansion because of the drop in pressure. Figure 3 also presents calculated temperature curves, which correspond to the height-time curves for the three yields shown and which indicate the expected cooling due to rise alone. These curves show the absolute temperatures of the fireball relative to that before rise commences, calculated on the assumption that the expansion is adiabatic (*i. e.*, neglecting heat losses due to radiation or convective mixing) and that the fireball is always at a pressure corresponding to that of the ambient atmosphere at its center line. The actual temperature will, of course, be much lower, due especially to the effects of convective dilution with ambient air. The purpose of these curves is, however, to show that at times of 100 seconds after fission or later, the cooling due to expansion has become in itself quite a significant factor, lowering the absolute temperature by more than 30% for large weapons.

As the fireball rises, it cools by radiation, by expansion due to the drop in ambient pressure, and by convective mixing with induced ambient air. During this rise, it generally approaches a mushroom shape. The mushroom cloud "stabilizes" (ceases to rise) at various levels, dependent on the size of the bomb and the meteorology. Clouds from small weapons may cease rising when they come to an inversion layer or at the base of the stratosphere. Clouds from very large weapons, because of their high thermal energy, penetrate into the stratosphere. Table III lists data presented by Schuert<sup>66</sup> for the average dimensions and elevation of the fireball cloud at 10 minutes after detonation for various weapon yields. The nature of the burst (*e g.*, surface burst, air burst etc.) apparently does not have a very marked influence in this late time. Meteorology does have some effect, especially on the upper cloud elevation and diameter, as discussed by Kellogg<sup>69</sup>

Schuert<sup>65</sup> indicates that the rise stabilizes in approximately six minutes, independent of yield, although the expansion of the mushroom diameter may continue for some 30 minutes for megaton devices. Glasstone<sup>18(p.23)</sup> reports that, for a 1-MT yield, the maximum altitude (25,000 to 50,000 ft) of the bottom of the mushroom head is attained in 8 to 10 minutes. For weapons in the megaton range, the top may rise to 130,000 feet. These values are in nominal agreement with those reported by Schuert

From Table III it is apparent that 300 sq mi/MT and 1000 cu mi/MT may be taken as nominal values for the area and volume of the stabilized cloud, respectively. Comparing these values with those of the maximum size fireball, it is evident that the fireball has entrained some 1000 times its volume of ambient air at the time the cloud has stabilized, assuming that the fireball was essentially at ambient pressure when it attained its maximum size. From an energy balance (see Table VI for necessary data), it can be shown that the entire energy of the weapon is not capable of heating this much air more than relatively few degrees. Consequently, it may be concluded that at the time of rise stabilization, the average cloud temperature has dropped essentially to ambient temperature.

*c. Growth and Cooling of Fireball:* In the earlier stages, the fireball expands because its pressure is dropping. At this stage it cannot mechanically engulf or entrain air because the pressure is above ambient. It can, however, encompass or assimilate more air because of heating of surrounding air above the luminescence point so that, by definition, this air becomes part of the fireball. Once the fireball pressure has dropped to essentially ambient pressure, it can engulf more air mechanically. At this stage, it is readily shown from an energy balance (neglecting cooling due to fireball rise) that the volume,  $V_f$ , and the mass,  $m_f$ , of the fireball are related to fireball temperature,  $T_f$ , by

$$V_f = (R/M)(Q_f/c_{hp})(1/P_a)[T_f/(T_f - T_a)] \quad * \quad (1)$$

$$m_f = (Q_f/c_{hp})/(T_f - T_a) \quad , \quad (2)$$

where:  $R$  is the gas constant, and  $c_{hp}$ ,  $M$ ,  $P_a$ , and  $T_a$  are the specific heat, molecular weight, absolute pressure, and absolute temperature of the

---

\* See Section on "Nomenclature" for detailed definitions and units

ambient (or engulfed) air, respectively. The term,  $Q_f$ , is the thermal energy delivered to the gas comprising the fireball and cloud. This may come either directly as thermal radiation or as the result of blast and shock. In future discussions it will be assumed, for purposes of argument, to be  $\frac{1}{3}$  of the total energy of the bomb. It is interesting to note from these equations that the fireball volume remains essentially constant even though it may be engulfing large amounts of ambient air, as long as the fireball temperature still remains high (say, above  $1000^\circ\text{K}$ , so that  $T_a$  is small compared to  $T_f$ ) and as long as the fireball or ambient pressure does not change (i.e., the fireball does not rise to any great extent). This comes about because cooling of the original fireball gas results in a volume contraction that compensates for the additional engulfed air volume. This is presumably the reason that the fireball volume approaches a so-called maximum size.

For  $P_a = 1$  standard atmosphere,  $c_{hp} = 0.27$  (Btu)/(lb)( $^\circ\text{F}$ ) and  $Q_f = 1.3 \times 10^{12}$  Btu/MT, the above equations may be rewritten as

$$V_f, (\text{cu mi/MT}) = 0.82 \left( \frac{T_f}{T_f - T_a} \right), \quad (3)$$

$$m_f, (\text{megatons/MT}) = \left( \frac{1340}{T_f - T_a} \right), \quad (4)$$

where  $T_f$  and  $T_a$  are in  $^\circ\text{K}$ .

From these equations it is apparent that, by the time the fireball has engulfed some 1.8 megatons of air/MT weapon yield, the average fireball temperature has dropped below  $1000^\circ\text{K}$ , and its volume is some 1 cu mi/MT. These values are based on an arbitrary assignment of thermal energy delivered to the gas. For small yields, energy transmitted to outer space may be very large and an even smaller degree of air engulfment would result in temperatures below  $1000^\circ\text{K}$ . These values also do not allow for pressure reduction due to fireball rise. This effect is probably small for small yields but can be pronounced for large yields. Thus, for small yields, the quantity of engulfed air that would result in temperatures below  $1000^\circ\text{K}$  is considerably less than 1.8 megatons/MT, while for large yields the fireball volume at the time the average temperature drops below  $1000^\circ\text{K}$  may be somewhat larger than 1 cu mi/MT.

From the values in Table II, it is apparent that the maximum size fireball need only engulf some 10 times its mass of additional air to drop the average temperature below  $1000^{\circ}\text{K}$ . By way of comparison, Table III indicates that at the time of rise stabilization the maximum-size fireball has engulfed more than several hundred times its original mass of air.

*d. General Discussion:* Some sources have suggested the possibility that temperatures within the fireball may remain high for considerably longer time intervals than indicated above. This suggestion is based on (1) visual observations of nuclear weapon detonations, (2) the possibility of surface attenuation of true interior bomb temperatures, and (3) time-regression interpretations based on radiochemical analyses of fallout particles.

In view of the data presented above, especially Glasstone's observation of nonluminescence after 1 minute for a 1-MT bomb and the 1000-fold ambient air dilution reported by Schuert after 10 minutes, the time required for the average surface temperature to drop to  $1000^{\circ}\text{K}$ , as given by the data of Figure 2, is probably also reasonably representative of the time required for the over-all average temperature of the fireball and cloud to drop to  $1000^{\circ}\text{K}$ . It is, of course, conceivable that local hot spots can exist in the fireball for periods much beyond those indicated for the averages in Figure 2. If, however, a significant portion of the fireball is at either a lower or higher temperature than indicated in Figure 2, it is the pessimistic extreme that would dictate the feasibility of any control measures designed to give effective (>90%) control.

The above has dealt largely with average temperatures in the fireball. It could be postulated that the radioactive bomb debris remains concentrated in a discrete volume that is very much smaller than the fireball or cloud, and that temperatures in such a discrete volume may be high for considerably longer periods of time than would be the case for the average cloud. If we assume that such a condition exists, then there must also be a hydrostatic pressure difference between this discrete volume and the surrounding cooler air because of the difference in density in adjacent columns of fluid. This hydrostatic pressure results in a motion or influx of surrounding air into this discrete volume. The magnitude of the velocity of such an influx,  $u$ , can be estimated by equating the kinetic energy of the influx to the potential energy associated with the hydrostatic

pressure difference to yield

$$u = \sqrt{2 g_L H (\Delta\rho/\rho)} \quad (5)$$

where  $H$  is height of the discrete volume,  $\Delta\rho$  is the difference in density between gases comprising the discrete volume and the surrounding gas,  $\rho$  is the density of the surrounding gas, and  $g_L$  is the gravitational acceleration. The ratio  $(\Delta\rho/\rho)$  depends on the magnitude of temperature differences involved. If the discrete volume is at a temperature very much above that of the surrounding gas, this ratio approaches unity. If the ratio is below 0.3, the temperature difference cannot be too great. Thus, if this discrete volume is several hundred or more feet high, the above equation predicts influx velocities of more than 100 ft/sec. The time,  $t$ , for such a jet to traverse the entire height or width of the discrete volume is given by

$$t = \frac{H}{u} = \sqrt{\frac{H}{2 g_L (\Delta\rho/\rho)}} \quad (6)$$

From this it is readily shown that, to traverse any discrete volume much smaller than the size of the maximum size fireball would take on the order of 10 seconds. The actual mechanism is, of course, considerably more complicated because of the influx of air over the entire surface of the discrete volume and the reduction in temperature difference as influx takes place. The above, however, is useful in assessing the order of the length of time that such a discrete volume might exist. It may be concluded, therefore, that if such a discrete volume of hot gases containing fission products existed, it could not exist for a period more than some 10 seconds, and for probably considerably less time, before it would be interdispersed by surrounding air.

The hydrostatic pressure gradient considered above is presumably the underlying reason for the toroidal circulation and ultimate mushroom shape observed in the fireball cloud. The bottom of the fireball drops to ambient pressure first. As the fireball continues to expand, the first influx of ambient air takes place at the center of the bottom of the fireball. This, in turn, initiates the toroidal circulation. As a result of this circulation, the cloud tends to flatten out, although the greatest flattening effect probably occurs when the cloud hits a temperature

inversion, such as commences at the tropopause. The toroidal circulation is also enhanced by the surface shear experienced by the rising fireball.

### 3. FIREBALL AND CLOUD DEBRIS

The debris in the fireball and cloud arises from several sources: (1) the bomb structure or supporting structure; (2) the fission products and residual fissionable material; (3) substrate induced into the fireball or cloud by the explosion; and (4) atmospheric dust.

The bomb itself involves on the order of 1 ton of metal/MT, although this value is highly variable depending on the nature and size of the weapon. With a tower shot, for example, the bomb debris may be many times this value because of the metal introduced from the tower. This value will also be considerably higher with the smaller weapons. Nevertheless, the nominal value has been used in Table II to assess the order of magnitude of bomb debris concentration in the fireball.

The relative amount of fission products in the fireball depends on the nature of the weapon. The ultimate quantity of strontium-90 formed is on the order of 1000 g/MT. The total fission products are on the order of 20 kg/MT. Here again, wide deviations are encountered, dependent primarily on the weapon design. With a so-called "clean" bomb, the fission yield may be considerably below the values indicated above. Table II gives the concentrations of strontium-90 in the maximum size fireball on the basis of 1000 g strontium-90/MT. It should be remembered, however, that this much strontium-90 may not exist in the maximum size fireball, because some of the strontium-90 may not be formed from its precursors until a much later time. Besides strontium-90 there are also several other nuclides of strontium, mostly with very much shorter half-lives. In the period 100 to 1000 seconds after fission, some 35% of the fission products may be in the form of one of the strontium nuclides (strontium-89, strontium-90, strontium-91, strontium-92, strontium-93, strontium-94), all being formed in approximately equal amounts. In this same period, up to 20% of the fission product may be cesium nuclides, including cesium-137.

The nature and quantity of the substrata induced into the fireball and cloud depends on the size and type of burst besides the specific physical characteristics of the substrate. Glasstone<sup>18(pp.24,26)</sup> states that, if only 5% of the bomb's total energy is spent in vaporizing debris, vaporized material is added to the fireball to the extent of 20,000 tons of

soil material/MT for a land-surface burst and 100,000 tons of water/MT for a water-surface burst. Also based on data presented by Glasstone<sup>18(p.210)</sup> for the size of crater formed by a contact surface burst, it may be estimated that the total soil and rocks hurled up amounts to some 4 to 7 megatons/MT. It is to be expected that a large part of this falls out immediately or is displaced laterally and does not actually enter the bulk of the fireball.

Dust is present in the lower atmosphere to the extent of some 0.01 grains/1000 cu ft (0.1 ton/cu mile). Thus, since the maximum-size fireball is approximately 1 cu mile/MT, and allowing for the elevated temperature, atmospheric dust in the maximum-size fireball is only some 0.02 ton/MT, which is negligible compared with the bomb debris of 1 ton/MT. At the time of rise-stabilization, however, atmospheric dust accounts for some 100 tons/MT, which is large compared with bomb debris but small compared with induced substrate debris for surface bursts.

#### 4. VAPOR PRESSURE AND MELTING POINT DATA

Vapor pressure and melting point data for pertinent elements and compounds are summarized in Appendix B. For the more important compounds, these data are shown plotted in Figure 5. In this figure the metallic component concentration, expressed as  $\mu\text{g}/\text{cu ft}$  (based on actual, *not* standard volume), corresponding to the vapor pressure of the compound (or to the vapor pressure of the metallic component in cases where the compound dissociates), is shown as a function of temperature. Solid lines represent actual data; dashed lines represent extrapolations. Also shown are the ranges of concentration corresponding to bomb debris and to strontium-90 in the maximum-size fireball, as taken from Table II.

It is apparent from Figure 5 that bomb structure debris, such as Fe (which would be in equilibrium with iron oxide), is all condensed out by the time the fireball temperature drops much below  $2000^\circ\text{K}$ . This is in agreement with the conclusions reached by Rand Corporation.<sup>47(p.14)</sup>

Strontium-90, if all formed, is probably present as the oxide and does not condense out until the temperature drops to  $1500^\circ\text{K}$ . Its precursor, rubidium-90, however, is probably in equilibrium with rubidium oxide and does not condense out until the temperature drops to some  $800^\circ\text{K}$ . This is, of course, an oversimplified picture. Strontium-90, for example, does not behave independently but depends on the quantity of all the other



isotopes of strontium present at the time. Whereas the fission yield of strontium-90 is some 5%, the total yield of all strontium isotopes is some 35%. However, because of the steepness of the SrO vapor pressure curve, the over-all results are not radically affected.

Vapor pressure of pure compounds is also not the complete story. For example, there is also a possibility of equilibrium of  $\text{Sr}^{90}\text{O}$  with the oxides of bomb debris (or substrate debris in the case of surface bursts). With such an equilibrium the vapor pressure of SrO may be lower than it would be over pure SrO. In fact, estimates based on Raoult's law indicate that at temperatures still above the melting point of FeO ( $1644^\circ\text{K}$ ) and for concentrations of FeO corresponding to bomb debris, the equilibrium vapor pressure of SrO above FeO is considerably less than would correspond to the strontium-90 content of the fireball. Thus, a high degree of solution of strontium-90 in the bomb debris is potentially possible. The actuality of this possibility is, however, contingent upon having all the strontium-90 formed at a time before the fireball temperature drops below the melting points for the debris condensates. It is in this connection that the fireball temperature history assumes a critical role.

From the data presented in Figure 2 and the other supporting data above, it may be concluded that, except for weapon yields larger than 10 MT, temperatures in the fireball are less than  $1000^\circ\text{K}$  (i.e., below the melting point of likely bomb debris) at times later than 100 seconds after fission. This implies that temperatures in the fireball drop to levels below which reaction with likely debris compounds may be expected before any of the critical fission products, strontium-90 and cesium-137 or their precursors, are primarily in a chemically reactive form.

## 5. PARTICULATE FORMATION

A rapid order-of-magnitude estimate of the size of particles formed during the cooling of the fireball can be made from mass transfer considerations. The rate of particle growth is limited by, among other things, the rate at which vapor can diffuse to the particle surface. The relationship which gives the maximum size to which a particle can grow in a given time is developed in Appendix D (Equation D-14) and plotted in Figure 6. This figure presents the size to which a particle can grow in a given time for various driving forces, expressed in terms of vapor concentration. The driving force is the difference in concentration between that of the material in the vapor phase and that corresponding to saturation

at the particle surface temperature. In preparing Figure 6, the diffusion coefficient for the vapor was taken arbitrarily as  $0.1 \text{ cm}^2/\text{sec}$ . For the types of compounds involved in the fireball at temperatures of 1000 to  $3000^\circ\text{K}$ , the diffusion coefficient may range from  $0.1$  to  $1 \text{ cm}^2/\text{sec}$ . A diffusion coefficient of  $1 \text{ cm}^2/\text{sec}$  would result in a particle diameter approximately 3 times that given by Figure 6.

As a first approximation, the driving force may be assumed to equal the initial concentration of the condensing material in the vapor phase. Using this concentration results in an overestimate of the particle size since the actual driving force is less than this, both because of the vapor pressure from the particle surface and because of the depletion of vapor from the gas phase as condensation progresses. Any additional limitation, such as time for nucleation, also results in a smaller particle than predicted by the above approximation, although this factor may be small for the time periods and particle sizes involved in this application.

It is apparent from the slope of the vapor pressure curves in Figure 5 that, in the region of debris condensation ( $2000^\circ\text{K}$ ), most of the debris vapor is condensed out if the gas temperature drops on the order of  $100^\circ\text{K}$  below the saturation temperature. From Figure 2, the rate of gas cooling in this region is of the order of  $1000^\circ\text{K}/\text{sec}$  for a small weapon yield and  $10^\circ\text{K}/\text{sec}$  for a very large weapon yield. Thus, the time available for particle growth is only about 0.1 second for a very small weapon and 10 seconds for a very large weapon. Table II indicates a bomb debris concentration of some  $20 \text{ } \mu\text{g}/\text{cu ft}$  for a small weapon and  $2 \text{ } \mu\text{g}/\text{cu ft}$  for a very large weapon. For these times and concentrations it is apparent from Figure 6 that, for an air burst, the particle diameter formed during condensation cannot exceed some 0.1 micron. Allowing for the fact that the diffusion coefficient may be up to 10 times the value of  $0.1 \text{ cm}^2/\text{sec}$  assumed in Figure 6, this maximum diameter may be as large as 0.3 micron. Allowing for vapor depletion, particle vapor pressure, and minimum time of growth, it is likely that the bulk of the bomb debris particles are not much smaller than 0.03 micron. Thus it may be concluded that the bomb debris probably forms particles in the range of 0.03 to 0.3 micron diameter.

If we assume that the fission products, such as strontium-90, condense out as particles of pure compound, a similar reasoning shows that the particle diameter can not exceed on the order of 0.01 micron and probably is in the range of 0.001 to 0.01 micron. It is likely, however,

that the fission products condense on the surface of other particulate debris which is already present at the time of fission product condensation. As is shown below, however, the question of whether or not fission products condense out as pure compounds is academic, since any fission product particles ultimately deposit on the other debris particles anyhow.

In the case of a land-surface burst, the vaporized debris concentration is on the order of  $10^4$  or more times that of the bomb debris. Since the size to which a particle may grow is a square root function of vapor concentration (Equation D-14), the particle size of this debris should be of the order of 100 or more times that of the bomb debris, neglecting the effect of any unvaporized debris. Thus the diameter of particles resulting from the condensation of the vaporized debris from a land-surface burst is expected to be largely in the range of 3 to 100 microns. In this case, however, the presence of additional unvaporized debris may result in a more rapid rate of cooling. In addition, condensation may take place on the unvaporized debris.

For a water-surface burst, vaporized salt is present at a concentration of some  $10^3$  to  $10^4$  times that of the bomb debris. However, the vapor pressure for NaCl is sufficiently high (close to that for AgCl in Figure 5) so that condensation does not take place until the fireball temperature drops below  $1500^\circ\text{K}$  and, hence, until further dilution with ambient air takes place. Thus the particle size of the resulting sodium chloride is probably somewhat smaller than that of the land-surface debris.

The above has simply considered growth by vapor diffusion. It is also possible for particles to grow by accretion or collision. For large particles ( $>1\mu$ ), in which case collision by the inertial mechanism becomes controlling, this growth process might be significant. For particles smaller than 1 micron, however, such a growth process is diffusional in nature. Since the diffusion coefficient for particles is orders-of-magnitude smaller than for the vapor, growth by this mechanism cannot be significant during the particle formation process. It could, however, become significant in the ultimate history of the cloud, involving a time period many-fold greater than that encountered during the condensation phase.

The effectiveness with which small particles deposit on larger ones by diffusion in a quiescent fluid is developed in Appendix D and is summarized by Equation D-10. This equation is depicted graphically in Figure 9, which gives the deposition time per transfer unit as a function

of the diffusion coefficient for the depositing particles and the concentration of the collecting particle, assuming that the collecting particles have a diameter of 10 microns and a density of 1 g/cu cm. The term transfer unit is a convenient measure of the effectiveness of deposition. The numerical relationship between transfer units and the fraction of depositing particles collected is illustrated in Table V. For example, a 95% collection of depositing particles on the surfaces of the larger collecting particles would correspond to 3 transfer units.

Assuming that strontium-90 condenses out as individual  $\text{Sr}^{90}\text{O}$  particles of 0.003-micron diameter in an air burst containing bomb debris to the extent of 10  $\mu\text{g}/\text{cu ft}$ , Figure 9 indicates that it would take 10,000 seconds to attain 1 transfer unit of deposition on bomb debris, if the debris particles were 10 microns in diameter. However, since the bomb debris particles are only some 0.1 micron in diameter and since deposition time varies as the square of collecting particle size, it would take only 1 second per transfer unit. In other words, 63% of the  $\text{Sr}^{90}\text{O}$  particles would have deposited on the bomb debris in 1 second, or 95% in 3 seconds. Even if the  $\text{Sr}^{90}\text{O}$  particles were as large as 0.01 micron and the debris concentration as low as 1  $\mu\text{g}/\text{cu ft}$ , 95% of the  $\text{Sr}^{90}\text{O}$  particles would deposit on the debris particles in 300 seconds. Thus, even if strontium-90 condensed out as individual particles of  $\text{Sr}^{90}\text{O}$ , the net effect would, in short order, be the same as though it had condensed out directly on the bomb debris. The only difference would be that in one case the  $\text{Sr}^{90}\text{O}$  would be molecularly dispersed over the bomb-debris particles' surfaces, and in the other case it would be present as discrete particles adhering to the surface.

The above assumes that the strontium-90 is in a condensable form not long after the bomb debris has condensed. If the strontium-90 does not form until much later times, the bomb debris concentration may have dropped to such low levels that the deposition time is very much longer. For example, if the strontium-90 does not become condensable until times corresponding to the rise-stabilized cloud, the bomb debris concentration is only some 0.01  $\mu\text{g}/\text{cu ft}$ , or of the same order as the atmospheric dust entrained with the ambient air at high elevations. In this case one would predict that it would take over 3000 seconds for 95% deposition. By this time the bomb debris concentration would have dropped still further and deposition of the strontium-90 would take place essentially entirely on the atmospheric dust particles.

Consider now a surface burst at times corresponding to rise-stabilization. The total cloud debris that previously passed through a vapor phase is present at a concentration of some 10 to 100 tons/cu mi. Figure 9 indicates that between a few hundred and a few thousand seconds are required for most of the strontium-90 to deposit on this debris, depending on whether the strontium-90 is depositing from the vapor phase (diffusion coefficient on the order of  $0.1 \text{ cm}^2/\text{sec}$ ) or as separately formed particles (diffusion coefficient on the order of  $0.01 \text{ cm}^2/\text{sec}$ ). This assumes, of course, that the debris particle diameter is 10 microns. For 100-micron debris particles, times are 100 times as long. It follows, therefore, that what strontium-90 deposits on debris particles does so largely on the smaller debris particles.

## B. FALLOUT

### 1. TYPE AND NATURE OF FALLOUT

Depending on the nature and size of burst, fallout can follow several distribution patterns. With all surface bursts, there is a tremendous quantity of fallout of relatively large particles (50 to 1000 microns) within a few hundred miles of the point of detonation. This fallout contains some 50 to 80% of the total radioactivity produced,<sup>73(p.130)</sup> although there is considerable doubt and speculation as to the exact values. Particles in the range of 10 to 100 microns carry for considerable distances but fall out before being distributed in the world's atmosphere. Smaller particles are distributed in the world's atmosphere to a variable extent, dependent on the size and type of burst. For air bursts there is essentially no local fallout.

With low weapon yields, the fireball cloud remains in the troposphere. Air in the troposphere circles the world but remains within relatively narrow latitudes. Thus, any fine debris from such a burst tends to be confined within those latitudes that correspond to the point of the detonation. Debris in this air is subject to extensive vertical mixing, scavenging by atmospheric dust, and scavenging by rain. It is generally believed that debris in the troposphere has a life of less than a few months before being deposited on the earth's surface or vegetation in one form or another.

Fine material that gets into the stratosphere, as with shots in the MT range, is apparently stored there for considerable lengths of time

before coming back into the troposphere. The mean storage time in the stratosphere has been estimated as ranging from 5 to 20 years. Libby<sup>37</sup> indicated a time of 10 years or a little less as the most recent value. In this sense, stratospheric fallout is often referred to as "delayed" fallout. Because of stratospheric circulation, material in the stratosphere not only circles the world, but is distributed longitudinally as well before re-entering the troposphere. It is in this sense that stratospheric fallout is often referred to as "worldwide" fallout, although this term is also applied to the finer portions of tropospheric fallout.

The exact mechanism by which stratospheric debris gets back into the troposphere is not actually known. It is currently believed to be the result of bulk interchange of air between the stratosphere and troposphere as the result of a shifting of the tropopause with season and latitude.<sup>37,280</sup>

Radiochemical analyses of fallout resulting from some of the earlier surface shots have indicated some marked separation of the various fission products. For example, the strontium-89 content of local fallout, after correction for strontium-89 decay, has been found to be considerably less than would be expected from fission yields on the basis of other fission products such as molybdenum-99. Since strontium-89 is a nuclide formed at very late times (see Appendix C) from inert gas precursors, this has been construed to mean that it did not condense out until much of the local fallout material had separated from the bulk of the fireball cloud. Recent, as yet unpublished, data, however, are preliminarily reported to show relatively little separation of the various nuclides in fallout. A more detailed study of available information is needed to clarify the interpretation. As previously discussed under "Fireball and Cloud," the early-condensing bomb debris would be expected to interact with soil debris. However, the subsequent condensation on, or mechanical scavenging by, the finer debris particles especially, can effectively collect late-forming nuclides. These same unpublished data are also reported to indicate that the bulk of strontium-90 in the fallout particles is water soluble, indicating it to be present as a surface deposit.

## 2. MECHANISMS AND RATE OF FALLOUT

There are, in general, two ways in which fallout can deposit on soil and vegetation. The particles can deposit directly, either by gravitational settling, by physical interception arising from the finite size of the particle, by inertial deposition from wind effects, by diffusion,

by electrostatic effects, or by migration in a thermal gradient. The fallout particles can also be scavenged by raindrops and deposited during rainfall, giving the so-called rainout. It is generally conceded that the bulk of soil deposition is the result of rainout.<sup>37,280</sup> Stewart,<sup>313,624</sup> in Great Britain, for example, has concluded that 95% of deposition is due to rainout. He also has found that the activity content of both rainwater and soil shows a similar variation with latitude, having a minimum value at the equator, a small peak in the middle of the southern hemisphere, and a large peak in the middle of the northern hemisphere. This effect has also been reported by Machta<sup>73(p.152)</sup> and others.<sup>37,72</sup> Stewart<sup>313</sup> also reports some indication of a seasonal effect on fallout rate in 1955 and 1956, the rate being highest in late spring and lowest in late fall. Air concentrations of strontium-90 showed a similar seasonal variation. This indicates that there is a seasonal variation in the rate at which strontium-90 is transferred from the stratosphere to the troposphere. Stewart<sup>313</sup> also found that the specific activity of rainwater decreased as the size of the shower increased, reflecting the local depletion of activity in the atmosphere as water scavenging continues.

Blifford<sup>183,381</sup> from both fallout and air concentration measurements in Washington, D.C., reported effective fallout velocities that ranged from 700 to 500,000 ft/day. The values on dry days averaged 2,700 ft/day and the values for wet days averaged 30,000 ft/day. Effective average dry fallout velocities measured by Stewart<sup>313</sup> in Great Britain, however, averaged only 200 ft/day. It is interesting to note that, assuming gravitational settling as the predominant mechanism in dry deposition, Blifford's average value corresponds to a 10- to 15-micron diameter particle, whereas Stewart's value corresponds to a 3- to 4-micron particle. Considering the widely different latitudes involved, this may reflect a real difference in the type of fallout particles involved in each case.

Campbell<sup>392</sup> has derived a theoretical equation for predicting the effect of stratospheric storage on ultimate soil concentrations of fission products. Although it involves several simplifications, it is nevertheless useful for indicating the types of trend to be expected. Campbell's result is shown in Figure 4 in both algebraic and graphical form. In the derivation of this relationship the following basic assumptions are made:

1. a continuous uniform weapons testing rate
2. transport of fission products to a storage space (say, the stratosphere) of essentially constant volume

3. complete rapid mixing in this storage space
4. a constant mean storage or residence time,  $t_s$ , in the fixed volume
5. no depletion in the soil other than that due to normal radioactive decay.

In the derivation he assumes that there is a constant volumetric rate of interchange of air between the stratosphere and troposphere. Material so carried into the troposphere is assumed to deposit rapidly (instantaneously) on the earth's surface, where it accumulates and undergoes normal decay. Normal decay during residence in the stratosphere is also allowed for. The mean storage time,  $t_s$ , is defined by

$$t_s = V/q \quad (7)$$

where  $V$  is the volume of the storage space and  $q$  is the volumetric rate of air interchange with the troposphere. It is the combination of this assumed fixed volumetric interchange rate with the fixed volume that leads to the postulate of a fixed mean residence time as expressed in Assumption No. 4 above.

Another way of looking at the problem, one that yields the same end result, is to consider the mass withdrawal rate,  $w$ , from the storage space in terms of a migration velocity,  $u$ , over some fixed area,  $A$ . Then

$$w = ucA \quad , \quad (8)$$

where  $w$  is the mass withdrawal rate of the nuclide at the time when the concentration of the nuclide in the storage space is  $c$ . Both  $c$  and  $w$  are, of course, variable with time. The mean storage time is then given by

$$t_s = cV/w = cV/ucA = V/uA \quad . \quad (9)$$

If the transfer out of the storage volume is the result of physical flow or interchange of air,  $u$  is the average velocity of this air through the interchange area,  $A$ . Hence  $q = uA$  and  $t_s = V/q$  as originally defined.

However, if the transfer out of the storage volume is the result of a migration of the nuclide alone, as by gravity settling,  $u$  is the migration velocity through the area,  $A$ . For example, if gravity settling



is the predominating mechanism, then  $u$  is equal to the terminal settling velocity of the fission product particles,  $u_s$ , and  $A$  is equal to the surface of the earth. The term  $t_s$  would still be a constant, given by  $V/u_s A$ .

Both of the above concepts of the mechanism of interchange yield the same final equation. The only difference lies in the way in which  $t_s$  is arrived at. It should also be noted that the Campbell relationship still holds if an intermediate holdup region (which may also be nonuniform in nuclide concentration), such as the troposphere, exists, provided that the retention time in this intermediate region is small compared with the stratospheric storage time,  $t_s$ .

Figure 4 presents a plot of Campbell's equation based on the decay rate of strontium-90. This figure depicts the soil activity in relative units as a function of time for various mean storage times,  $t_s$ . It is apparent from this figure that, with a stratospheric storage time of 10 years, the ultimate soil activity for continuous uniform weapons testing would be some 80% of that with no stratospheric storage at all. It would take some 100 years, however, to approach this ultimate activity level. Even with a storage time of 200 years, the ultimate soil activity level would still be some 17% of that with no storage. The greatest effect of stratospheric storage is on the soil levels in the early years after the start of testing. If testing should cease at any time, the effect of storage time on soil activity level would become more pronounced.

### 3. STRONTIUM-90 IN THE ATMOSPHERE

Russian measurements<sup>527</sup> of strontium-90 in the troposphere at 10,000 to 23,000 feet in February-May 1955 indicated a strontium-90 content of  $3 \times 10^{-7}$  to  $9 \times 10^{-6}$   $\mu\mu\text{g}/\text{cu ft}$ , averaging about  $3 \times 10^{-6}$   $\mu\mu\text{g}/\text{cu ft}$ . No significant variation with height was found. A summary<sup>72, 73(p. 619)</sup> of surface air concentration measurements over the period 1952-55 shows a range from  $2 \times 10^{-9}$  to  $4 \times 10^{-6}$   $\mu\mu\text{g}/\text{cu ft}$ . For 1955, the average is about  $8 \times 10^{-7}$   $\mu\mu\text{g}/\text{cu ft}$ , with a range of  $\pm$  three-fold.

Stratospheric air filter data,<sup>72</sup> taken in 1957 at 50,000 to 90,000 ft, indicate a marked variation with altitude, with a peak concentration at 65,000 ft. The average peak concentration corresponded to  $1.5 \times 10^{-4}$   $\mu\mu\text{g}/\text{std cu ft}$  or  $1.1 \times 10^{-5}$   $\mu\mu\text{g}/\text{actual cu ft}$ . Integration of the data over the entire range of altitude indicated a stratospheric content of 1800 grams of strontium-90 in 1957. The above values for

stratospheric air are uncorrected for the collecting filter efficiency, which was believed to be only 25%.

Thus, correcting for filter efficiency, the stratospheric content in 1957 was 7200 grams of strontium-90 ( $\approx 7$  MT). The tropospheric content in 1955, assuming a uniform distribution over a depth of 35,000 ft, would be estimated at 600 grams of strontium-90 ( $\approx 0.6$  MT) based on the Russian data and 150 grams strontium-90 ( $\approx 0.2$  MT) based on the data reported by HASL.<sup>72</sup>

Stewart<sup>64</sup> also found that a very sharp rise in the concentration of activity in the atmosphere occurred at an altitude of 40,000 ft, although his data did not extend above 48,000 ft.

From the above it is apparent that large amounts of strontium-90 are now stored in the stratosphere, compared with the troposphere. Thus, a large portion of future fallout will be stratospheric in origin. No data were found on the effective size of strontium-90-bearing fallout particles.

### C. STRONTIUM-90 ENTRY INTO FOOD

Strontium-90 in fallout can enter vegetation either through the soil or through the foliage. In the latter case it need not necessarily be absorbed within the tissue of the foliage, since any surface deposit is still passed on to cows and thence through milk to man. From the standpoint of potential fireball control measures, the fate of strontium-90 after it is deposited in or on vegetation is of little concern. However, the details of how it gets into or on vegetation may have an important bearing on the feasibility of certain control measures.

A large amount of the literature on fallout uptake by vegetation has tacitly assumed that the primary entry route is through the soil. However, most of the available data aimed at resolving this problem indicate, at least superficially, that direct deposition on the foliage is a large, or major, factor. Libby<sup>32</sup> points out that measurements made in 1953-54 indicate that the strontium-90/calcium ratio of plants is several times that of the soil in which the plants are grown. From these data he concludes that half of the total strontium-90 content of alfalfa is due to direct fallout and that, for general forage, an even greater percentage is direct. Menzel<sup>88,85</sup> reported that, relative to calcium, only 40% of strontium in the soil enters plants such as barley, buckwheat, and cow-peas. If this factor, which has been questioned by more recent data,<sup>747</sup> is applied to

the data reported by Libby, it appears that only 20% of the strontium-90 enters through the soil.

Bryant<sup>719</sup> measured the strontium-89/strontium-90 ratio in range grass, rain, and soil during corresponding time periods ranging from March 1956 to January 1958. Activity ratios of 10 to 20, 15 to 40, and 2.1 to 2.4, respectively, were obtained. From his data it can be calculated that from 23 to 54% of the strontium-90 content of the grass came in through the soil.

Booker<sup>712</sup> measured the cesium-137 content of milk as 0.40  $\mu\mu\text{c}$  cesium-137/g dry skimmed milk in 1956, in England, while Anderson<sup>692</sup> obtained a value of 0.31  $\mu\mu\text{c}$  cesium-137/g dry milk in 1956, in the United States. Romney,<sup>946</sup> in tests with barley and four other crops grown in a greenhouse, found that, for a given soil concentration, cesium uptake was very low compared with strontium uptake, averaging only  $\frac{1}{25}$  as much for barley grain and  $\frac{1}{69}$  for barley straw. From this combination of data it is possible to estimate the relative soil-to-foilage uptake of strontium-90 as shown below. From a series of material balances, the following relationship can be derived:

$$\eta_A = \frac{1 - \left( \frac{\beta_{y, AB}}{\beta_{s, AB}} \right) \left( \frac{\beta_{c, A}}{\beta_{c, B}} \right)}{1 - \left( \frac{\beta_{s, B}}{\beta_{s, A}} \right)} \quad (10)$$

where

- $\eta_A$  = fraction of total component A in plant that has entered through the soil
- $\beta_{c, A}$  = ratio of concentration of component A in milk to that in cow feed
- $\beta_{c, B}$  = ratio of concentration of component B in milk to that in cow feed
- $\beta_{s, A}$  = ratio of concentration of component A in plant to that in soil
- $\beta_{s, B}$  = ratio of concentration of component B in plant to that in soil
- $\beta_{s, AB}$  = ratio in milk of component A to component B
- $\beta_{y, AB}$  = ratio in bomb fission products of component A to component B

This relates the fraction of component A (which may be taken as strontium-90), that comes in through the soil, to measured ratios of concentration in milk of component A to component B (which may be taken as cesium-137) and to the various discrimination ratios for each component in going from soil to feed and feed to milk.

From Comar's work,<sup>747</sup> the ratio of strontium/calcium in milk to that in feed is 0.13. From estimates of a cow's diet and milk production it is estimated that  $\frac{1}{3}$  of the cow's calcium intake appears in the milk. Thus  $\beta_{c,A}$  is 4% of the strontium-90 in feed. From Romney's data, the ratio  $(\beta_{s,B}/\beta_{s,A})$  may be taken as 0.04. If the concentration of strontium-90 is taken as 5  $\mu\text{c}$  strontium-90/g dry milk (an average of values reported by Booker and Libby for 1956) and the concentration of cesium-137 is taken as 35  $\mu\text{c}$  cesium-137/g dry milk (the average of the data of Booker and Anderson),  $\beta_{s,AB}$  is found to be 0.10 after converting from an activity to a mass basis. The value of  $\beta_{y,AB}$  is between 0.5 and 1. The value of  $\beta_{c,B}$  is unknown but may be assumed to be in the range of 30% to 100% of the cow feed. On this basis it is found that  $\eta_A$  may range from 0 to 80%, the answer being very sensitive to the discrimination ratios involved.

From all of the above it is concluded that a sizable fraction of strontium-90 may come in through either the soil or the foliage. In the case of Bryant's data, the local circumstances of frequent fogs may accentuate the relative magnitude of direct foliar deposition. In all cases, however, it must be borne in mind that, at the time the data were taken, the levels of strontium-90 in the soil were relatively low. Currently they are some six times as high and will go considerably higher as stratospheric fallout continues to accumulate. Thus it is likely that, in the future at least, the predominant mode of entry of strontium-90 into or onto feed will be through the soil.

#### D. SUMMARY

The following summarizes those factors that have the greatest bearing on the immediate objective of evaluating possible control mechanisms:

1. Effective control (>90%) of strontium-90 and cesium-137 can be achieved only by action applied at times later than 100 seconds after fission, unless means can be found for controlling the inert gas precursors.
2. With weapon yields smaller than 1 MT, average fireball temperature drops below 1000°K at a time earlier than

100 seconds after fission. With weapon yields between 1 MT and 10 MT, this same condition probably prevails, although present knowledge is not adequate to be entirely conclusive.

3. For an air burst, bomb debris particle diameter is expected to be in the range of 0.03 to 0.3 micron.
4. The following are order-of-magnitude concentrations of debris in the fireball and cloud, expressed in tons/cu mile.

	MAXIMUM-SIZE FIREBALL	RISE-STABILIZED CLOUD
Bomb debris	1	0.001
Vaporized surface debris*	$10^4$ to $10^5$	10 to 100
Unvaporized surface debris*	$10^5$ to $10^7$	100 to 10,000
Atmospheric dust debris	0.01	0.1

---

\* For surface burst only

5. For an air burst, strontium-90 is deposited either on the bomb debris or on atmospheric dust in the subsequent cloud.
6. For a surface burst, strontium-90 is deposited largely on the smaller debris particles.
7. Fallout occurs predominantly in the form of rainout.
8. Large amounts of strontium-90 are now stored in the stratosphere and a large portion of future fallout will be stratospheric in nature. Mean storage time in the stratosphere is currently estimated as somewhat under ten years.
9. Deposition of strontium-90 on or in vegetation may occur through both the roots and the foliage. It is likely that in the future, if not now, the primary mode of entry will be through the soil.

## VII DISCUSSION OF POSSIBLE CONTROL MEASURES

### A. MEASURES INVOLVING PHYSICAL CHARACTERISTICS

Any change in physical character of the strontium-90 or strontium-90-bearing particles, aimed at potential reduction of the ultimate hazard, would be concerned with either increasing or decreasing the fallout or deposition velocities of the particles. As such, the change in physical character would be concerned primarily with a change in effective particle size. The following paragraphs discuss the potentials along these lines in terms of result to be achieved

#### 1. INCREASE STORAGE TIME

Control could be achieved by placing all fission products in the stratosphere and holding them there long enough to permit decay of their activity. From Figure 4 and the previous discussion thereof, it is apparent that for continuous long-time weapons testing an order-of-magnitude effect could be achieved by this means only if the stratospheric storage time were increased from the present period of some 10 years to at least several hundred years. This is not feasible for the following reasons:

- a. The storage time in the stratosphere is currently believed to be controlled by a physical interchange of air between the stratosphere and troposphere. On this basis, nothing short of worldwide weather control could achieve an increase in storage time.
- b. Assuming that the air interchange rate discussed above is not the controlling factor, the only other conceivable mechanism of stratospheric fallout control would involve reducing the settling velocity of the strontium-90-bearing particles. From the definition of storage time in these terms, namely,  $t_s = V/u A$ , the settling velocity of the particles would have to be made less than 100 ft/year to achieve a storage time of several hundred years. From Figure A-5 (Appendix A) this means that the particle diameter must be less than 0.03 micron. Assuming that particles of this size could be made, reference to Figure 8 will indicate that such particles would probably not be stable for the length of time required, as indicated below.

Figure 8 presents a basis for estimating the stability of various sized particles in the atmosphere. This figure gives the time required for

the deposition of small particles on atmospheric dust to the extent of one transfer unit, for various concentrations of atmospheric dust particles. It assumes simple diffusional deposition and is based on the same relationship as Figure 9 (previously discussed). In order to allow for the effect of size distribution of atmospheric dust, the atmospheric dust concentration is expressed in the form  $n_b D_b$ .

Data on the size distribution of natural dust in the stratosphere are essentially nonexistent. Crozier and Seely<sup>406</sup> present data which indicate a value of  $n_b D_b$  of about 1 [(particles/cu cm)(microns)] at 10,000 feet. Because of their method of sampling (impactor) and evaluation, it is possible that the smaller particles are missed and that the actual value of  $n_b D_b$  is higher. On the basis of these lower altitude results, one might expect that the value of  $n_b D_b$  is of the order of 0.1 in the stratosphere. Figure 8 indicates that particles of 0.03 micron would be effectively scavenged by this natural dust in a period of the order of 10 years. Thus, the effective size of such particles would be essentially that of the stratospheric dust.

- c. For a surface burst, particles of 0.03-micron diameter would be expected to be scavenged to a significant degree by the fine debris in the fireball cloud (see Figure 9 and previous discussion).

## 2. INCREASE LOCAL FALLOUT

By making the strontium-90-bearing particles large enough, they could be made to deposit locally within a restricted area. To do this, the strontium-90 must have an effective diameter of some 100 microns or larger. Smaller particles would be carried excessive distances. There are three conceivable ways in which this can be accomplished: (1) the vaporized strontium-90 and/or other debris can be allowed to grow to a sufficiently large size during the condensation process; (2) the strontium-90 can be caused to condense on large debris particles; (3) the strontium-90-bearing particles can be mechanically scavenged by large debris particles.

It is obvious from Figure 6 and the previous discussion thereof that there is insufficient time at elevated temperature to grow particles to a diameter of 100 microns. Even if there were sufficient time, nucleation processes would be active in producing an appreciable quantity of much finer particles.

Strontium-90 could be caused to condense on large ( $>100\mu$ ) debris particles. However, as discussed previously, they will tend to concentrate on smaller debris particles. If there are small debris particles present, as there will be from the volatilized bomb and substrate debris components, the ultimate success of this process would require mechanical scavenging of the smaller debris particles by large ones. Actually this process is present to some extent in all surface bursts.

Thus we are left with mechanical scavenging as the remaining ultimate way in which increased local fallout might be achieved. Details of mechanical scavenging are discussed in Appendix E. It is concluded there that, for the most effective scavenging, the scavenging material should have as small a particle size as possible. However, from the standpoint of ultimately achieving fallout in a distance of less than a few hundred miles, the scavenging particle diameter cannot be less than some 100 microns. Although the available bases for assessing scavenging efficiency are relatively poor, it is estimated in Appendix E that scavenging requirements for effective control of 0.1- to 1-micron particles (the size range most difficult to scavenge) would be on the order of  $10^5$  tons/sq mi of cloud, assuming scavenging particles  $100\mu$  in diameter. This quantity would have to be supplied on the basis of the rise-stabilized cloud, since the scavenging process would occur over a period of many minutes after detonation. Since the area of the rise-stabilized cloud is some 300 sq mi/MT, the total requirement of scavenging material would be upwards of 30,000,000 tons/MT in order to be effective. This is a tremendous quantity.

If the strontium-90-bearing particles, instead of being 0.1 to  $1\mu$  in diameter, were effectively 10 microns or larger, it is estimated that target efficiencies (see Appendix E for discussion of target efficiencies) would be of the order of 0.5 when scavenging with 100-micron particles. Thus, from Figure 10 (also discussed in Appendix E), scavenging requirements would be only some 2000 tons/sq mi of cloud. With surface debris volatilized in the fireball and cloud, it is likely that the strontium-90 will be attached to debris particles in the size range of 3 to 100 microns, as was indicated in Section VII-A-5. Thus, the scavenging requirement of some 2000 tons/sq mi estimated on this basis should be reasonably realistic. This quantity would correspond to a total scavenging requirement of some 600,000 tons/MT. While this is a sizable quantity, it is one within the realm of feasibility.



The above estimates of scavenging requirements have neglected electrostatic charging of scavenging particles. Such charges would arise during the dispersion of the scavenging material and would probably tend to increase scavenging effectiveness. Because of the relatively high ionic conductivity in the fireball and cloud resulting from the elevated temperature and the presence of ionizing radiation, it is doubtful, however, whether such charges could be sustained to any significant extent.

It should be emphasized, too, that the basis for the above estimates is highly simplified and superficial. Not only are fundamentals relatively undeveloped, but the necessary basic fireball and cloud data are not known in sufficient detail. In addition, the actual process is quite complex. The above has been based on mechanical scavenging of strontium-90-bearing particles. Actually, scavenging particles in the quantity of 600,000 tons/MT would correspond to concentrations of 600,000 tons/cu mi in the maximum-size fireball and 600 tons/cu mi in the rise-stabilized cloud. Such concentrations would also act as effective surfaces for strontium-90 condensation. The diffusion coefficient for the strontium-90 vapor would be somewhat over  $0.1 \text{ cm}^2/\text{sec}$ . From Figure 9 it is apparent that it would take less than 10 seconds for one transfer unit of the strontium-90 vapor to deposit on scavenging particles at these concentrations if they were 10 microns in diameter (which is the basis for Figure 9). Since the scavenging particles would actually be 100 microns in diameter, it would take some 100 times as long, but still less than 1000 seconds. Thus strontium-90 could effectively deposit on such scavenging particles in addition to depositing on the finer debris, which would then have to be mechanically scavenged. These superimposed effects would make for lower required quantities of scavenging material.

Since the methods for estimation are subject to considerable question, it is well to review this process in the light of known field data. For surface bursts, over a million tons/MT may be raised from the ground by the detonation. A large part of this is probably moved laterally or falls back soon after being raised. Thus, probably only a few hundred thousand tons/MT represents material actually carried into the cloud and which can act as a scavenging agent. Of this material, a large portion that does not vaporize and condense probably consists of relatively coarse particles (several hundred to several thousand microns in diameter) for the kind of soil sites that have been used. Yet, despite this, it is believed that some 50 to 80% of the activity (or roughly 1 transfer unit) is contained in the local fallout.

Scavenging effectiveness is directly proportional to the amount of scavenging material and inversely proportional to the square of the scavenging particle diameter (see equation shown in Figure 9) for the case where diffusional deposition is controlling. In the light of the above it would seem reasonable to expect that marked increases in local fallout can be achieved by reducing the substrate particle size, so that not only would more such material be transported into the cloud, but what would be so transported would be more effective as a scavenging agent. One of the greatest uncertainties lies in lack of information on the stability of particle adhesion to the scavenging material. Adhesion will probably be adequate with submicron particles and condensed vapor. Adhesion with depositing particles in the 10- to 100-micron range is uncertain, however.

The practical application of substrate control could take any one of several forms: (1) selecting the site so that the substrate would be of the desired size range; (2) special preparation and placement of substrate to desired specifications; (3) external application of scavenging material to the cloud after bomb detonation, as by planes or rockets. Considering the quantities of scavenging material required, the latter will probably be economically prohibitive as well as posing formidable engineering problems in the matter of securing reasonably uniform distribution of such large quantities at relatively early times in the cloud history.

The first alternate would be the least expensive, although it might not always be compatible with other considerations. Certain sands, for example, some inland Florida deposits, are comprised of particles primarily in the 100 to 150 mesh size range (equivalent to 147 to 105 microns diameter). The second alternative would be the most flexible but would incur a cost of several million dollars/MT, this cost depending on the site location and the source of desired substrate deposits.

From the standpoint of obtaining the maximum scavenging effect, the substrate should not only be of a specific minimum size range, but it should be unconsolidated in nature, or become so when subjected to heat, in order to permit the maximum amount to be carried up into the fireball cloud. Shaping of the substrate might also be useful in this respect.

### 3. ALTER FALLOUT DISTRIBUTION

By changing the effective size of fallout material, the immediate rate of fallout would be altered. Over the long term, however, atmospheric

concentrations would change to compensate for the altered fallout velocity so that there would be no net long range effect on worldwide deposition rates. This follows from the fact that, over the long term, mass balance considerations dictate that the worldwide fallout rate must equal the production rate of fissionable material in weapons testing. This statement is incorrect to the extent that it does not allow for variations in decay of radioactivity because of altered storage times. This factor, however, has been treated separately in a previous section.

Thus, while altered effective particle size cannot change long-term worldwide deposition rates, it could conceivably change the distribution of such deposits between soil and foliage because of the different deposition mechanisms that might be operative in each case. As will be shown below, however, a consideration of the specific factors involved leads to the conclusion that alteration of fallout particle size in the fireball or cloud has essentially no potential as a control measure from this viewpoint.

The bulk of fallout ultimately is acquired by the soil. During the nongrowing season, the soil receives all of the fallout directly; during the growing season, part of it. Much of the foliar uptake is also ultimately returned to the soil as the result of plowing and plant decay. Thus any change in effective particle size of strontium-90-bearing particles that might result in momentarily reduced fallout rates would have little long-term effect on total soil deposition. Consequently, if the prime mode of entry of strontium-90 to foliage is through the soil, a change in effective particle size of strontium-90-bearing particles would have little long-term effect on foliar uptake. As indicated previously, it appears that uptake from the soil will become the primary mode of entry in the future, if this is not already the case.

If rainout is the primary mechanism for bringing strontium-90 to the plant (either through the soil or to the foliage), a change in effective particle size of strontium-90-bearing particles cannot alter the long-term uptake since it would not alter the distribution between soil and plants, although the momentary rate of deposition on both could be altered. From calculations such as those of Greenfield,<sup>238</sup> the scavenging effectiveness of rainfall is very high for particles outside of the size range 0.1- to 1-micron diameter. For particles in the 0.1- to 1-micron range, the scavenging effectiveness is significant to moderate on an absolute basis (10 to 30%). Thus it is even doubtful if a radical momentary

change in rainout rate could be achieved by control of the size of strontium-90-bearing particles.

If the primary mode of entry to the plant were by dry fallout on the foliage (which is not believed to be the case), a change in the effective size of strontium-90-bearing particles could be beneficial. Such a change would have to be in the direction of reducing dry fallout, and hence increasing rainout. This means that the particles must be made either larger than 1 micron or smaller than 0.1 micron on the basis of Greenfield's<sup>238</sup> estimates. From a consideration of particle growth rates, previously discussed in conjunction with Figure 6, there is little opportunity for growing particles to a size much larger than 1 micron without very large controlled additions of material to the fireball. Thus the control of the effective size of strontium-90-bearing particles must be concerned primarily with producing particles smaller than 0.1 micron in diameter. As will be shown in the next paragraphs, particles smaller than 0.1 micron would not be stable in the lower atmosphere for a period of more than a few weeks before they would be scavenged by atmospheric dust particles. Thus any changes in the size of strontium-90-bearing particles that are made in the fireball cloud would probably not be reflected in the ultimate effective size of those particles.

Data on both size distribution and concentration of atmospheric dust are very meager, even for the lower atmosphere. Junge<sup>41, 510, 511, 671</sup> presents various data from which it may be concluded that the particle concentration in the lower atmosphere corresponds to a value of  $n_p D_p$  in the range of 10 to 1000 (particles/cu m)(microns), averaging about 100. Various other data indicate that the dust content of the lower atmosphere usually ranges from 0.01 to 0.1 grains/1000 cu ft, with a "mean" particle diameter in the range of 0.3 to 3 microns. Although the variety of usages of "mean" diameter makes most such data of questionable value, they can be used as a means for obtaining a rough crosscheck. Figure 7 gives a plot for converting from particle size and concentration to the corresponding value of  $n_p D_p$ . It will be seen from Figure 7 that for a particle size range of 0.3 to 3 microns and a concentration range of 0.01 to 0.1 grains/1000 cu ft, the value of  $n_p D_p$  will range from approximately 10 to 1000.

Since a 0.1-micron particle has a diffusion coefficient of approximately  $10^{-5}$  cm<sup>2</sup>/sec in the lower atmosphere (Figure A-6, Appendix A), it is apparent from Figure 8 that 0.1-micron particles could be stable

(i.e., exist without depositing on atmospheric dust particles) for a period of weeks only. On the same basis, 1-micron particles could be stable for a period of a few years. Actually, however, 1-micron particles are stable for even shorter periods of time since Figure 8 allows only for diffusional deposition. With particles as large as 1 micron, both inertial mechanisms and gravity settling provide additional means for particle deposition and flocculation.

## B. MEASURES INVOLVING PHYSICO-CHEMICAL CHARACTERISTICS

The strontium-90-bearing particles might be altered chemically to so change either the phase, solubility, or chemical reactivity as to reduce the ultimate ingestive hazard.

### 1. CHANGE OF PHASE

From Figure 5 and the previous discussion it is apparent that strontium-90 in either the troposphere or stratosphere must be in the solid phase at ambient temperatures if it is present as the oxide. By so altering the strontium-90 compound as to provide one that would be gaseous at ambient temperature, it is conceivable that direct leaf deposition might be reduced or that stratospheric storage time would be increased. From the previous discussion it is clear, however, that there is little potential in these directions, even assuming that a gaseous compound of strontium-90 were available. There are also no known stable inorganic compounds of strontium that have a sufficiently high vapor pressure (more than  $10^{-18}$  mm Hg) at ambient temperature to permit strontium to be in the vapor phase at even the lowest tropospheric concentrations. The most volatile are probably the halides (see Figure 5).

### 2. CHANGE OF SOLUBILITY OR REACTIVITY

Various measurements of fallout particles have indicated that at least a major portion of the strontium-90 is water soluble. It is likely that strontium-90 is present as the oxide, some possibly as the halide. With the exception of the fluoride, the halides are highly soluble in water. The fluoride has a moderate solubility (Table IV). The oxide will hydrolyze in water to form the hydroxide. Thus, in order to reduce the ultimate solubility or reactivity of strontium-90, it will be necessary to provide some means for either changing the type of compound formed, enmeshing (or dissolving) the strontium-90 oxide or halide in an inert

material, or coating strontium-90-bearing particles with an impervious or inert material.

*a. Change of Compound*

(1) *Inorganic*: Table IV lists the solubilities of some of the least soluble inorganic compounds of strontium. With the exception of the boride, the least soluble is the carbonate. However, this still has a relatively high water solubility, let alone acid solubility. Its solubility is comparable to that of  $\text{CaCO}_3$  and  $\text{CaF}_2$ , both of which are considered soluble from the standpoint of plant nutrition.

Although no data are available, the boride is probably extremely insoluble. Powell<sup>1041a(p.146)</sup> states that the borides of the alkaline earth metals (formula  $\text{MB}_6$ ) are not attacked by moisture, air, or dilute hydrochloric acid but are soluble in nitric acid. These borides are also stable in the presence of carbon at elevated temperature.

Considering the oxidizing conditions in the fireball cloud, it is difficult to conceive of any method for forming the boride without modifying the fireball cloud. To maintain reducing conditions in the fireball would require addition of dry organic matter in quantities corresponding to approximately 10% of the mass of air in the fireball and cloud. In addition, reducing conditions would have to prevail at times late enough for, at least, most of the krypton-90 to have decayed, or later than 100 seconds after the detonation. Reducing conditions would also have to prevail at temperatures high enough to permit formation of the boride. Considering the values of fireball or cloud mass given in Tables II and III, this would require the addition of between 30,000 and 100,000,000 tons of organic matter/MT, probably on the order of 1,000,000 tons/MT, besides the addition of sufficient boron to accommodate some components of the bomb debris, the surface debris, and any ash from the organic matter.

It is interesting to note at this point that the heat of combustion of some 100,000 to 200,000 tons of carbon or dry organic matter/MT will be equivalent to the entire (not just thermal) energy liberated by the bomb, depending on the degree of completeness of combustion. Thus the heat from such additions would serve to maintain fireball temperatures for longer periods of time than would otherwise exist.

Compounds such as  $\text{SrB}_6$  are thermodynamically unstable and their apparent stability is primarily a matter of slow reaction rates. Data such as those given by Powell<sup>10414</sup> are probably based on observations with bulk material. It is likely that, when dealing with very fine particles, both solubility and reactivity of  $\text{SrB}_6$  may be quite appreciable in the lengthy periods of time involved in both atmospheric and soil storage.

Before giving this possibility any further consideration it will be necessary to perform a detailed study aimed at evaluating: (1) the solubility or availability of  $\text{SrB}_6$  under soil conditions, especially when present in fine particulate form; (2) the stability of  $\text{SrB}_6$  in air at various temperatures; (3) the thermodynamics of the Sr-B and B- $\text{O}_2$  systems to determine conditions necessary for the formation of  $\text{SrB}_6$  and the adequacy of carbon or hydrogen as reducing agents; and (4) the consequences of addition of such large quantities of carbonaceous materials insofar as hazards of radioactive carbon and modification of weapons effects might be concerned.

(2) *Organic*: Certain organic compounds, such as dye lakes, are highly insoluble, although no specific data are available. The use of organics, however, would require external addition to the fire-ball cloud at times late enough to avoid temperatures higher than, say, 700°K. This would also involve a major engineering problem to secure distribution in the cloud at predetermined times.

Quantities of such dye lakes would have to accommodate all lake-forming elements in the cloud to insure that reaction with strontium-90 was achieved. Since a large portion of any debris is probably capable of forming such lakes, this means an addition corresponding to the order of magnitude of the total debris in the cloud. Since organic materials of this type cost on the order of a few dollars/lb, this means that any such treatment would be restricted to air bursts for economic reasons. For surface bursts, chemical costs would probably be upwards of \$100,000,000/MT.

As in the case of the borides, the stability of dye lakes may not be adequate for the time periods involved, despite their normal apparent insolubility. This is especially true in the case of organics, which are subject to radioactive deterioration in the cloud, photochemical action in the atmosphere, and bacterial or enzyme action in

the soil, in addition to normal solubility and reaction considerations. The problem of long-time soil stability might be alleviated somewhat if the organic matter stabilized the suspension of the strontium-90-bearing particle sufficiently to allow the ground waters to carry it to greater depths rather than permitting it to be fixed in the upper soil layers.

The use of organic reagents also presents the possibility of adding them continuously to the stratosphere in the form of aerosols rather than adding them to the cloud. This would have the added advantage of counteracting past accumulations of strontium-90 as well as future ones. On the basis of accommodating all the dust in the stratosphere, it is roughly estimated that such additions to the stratosphere, if feasible from all other standpoints, would require the continuous addition of upwards of 1 ton/hour and probably on the order of 100 tons/hour. The annual chemical cost of such a venture would, therefore, probably be on the order of \$1,000,000,000/year.

In view of the above it must be concluded that the use of dye lakes for forming insoluble or nonreactive strontium-90 does not present a very attractive potential from either technical or economic considerations, although the possibility cannot be completely discarded on the basis of current knowledge. Conditions for obtaining reaction between strontium-90 and the organic reagent to form a lake may constitute another limitation that requires detailed study. It should be remembered, however, that as long as the organic reagent is associated with the strontium, reaction need not occur immediately. Reaction occurring at any stage prior to deposition on the soil or vegetation would be sufficient.

*b. Embedding:* The strontium-90 hazard could be alleviated by embedding the strontium-90 compound or strontium-90-bearing particles in a matrix of insoluble material. For example, particles of molten silica or iron oxide could serve as a solvent for strontium-90. The strontium-90 could dissolve directly from the vapor phase (or from the vapor phase of its precursor, rubidium-90). Such molten matrix material could also act as a solvent for any strontium-90-bearing particles that deposited mechanically on the matrix droplets. Examination of fallout material from past shots has shown that actions of these types do take place.

The basic requirement for control by embedding strontium-90 in a matrix material is that the matrix material be above its melting point at a temperature sufficiently low for the vapor pressure of



strontium-90 (or any of its compounds or precursors) over the matrix material to be small compared with the partial pressure of the Mass-90 chain constituents. Calculations, assuming Raoult's law and assuming bomb debris to be primarily iron, have shown that the equilibrium vapor pressure of SrO above FeO will be many-fold less than would correspond to the total Mass-90 chain content of the fireball at temperatures somewhat above the melting point of FeO (1644°K). Similar calculations indicate that at the melting point of  $\text{Fe}_3\text{O}_4$  (1870°K) only a minor portion of the Mass-90 chain could be dissolved as SrO. It is likely that any iron from the bomb would exist as  $\text{Fe}_3\text{O}_4$  in the condensed phase. Thus, on this basis, it is unlikely that SrO would be dissolved to any major extent in the iron from bomb debris. However, major deviations from Raoult's law are not unlikely. In addition, the presence of other debris could result in a lowering of the melting point of the iron oxide. Because of the relatively high vapor pressures of rubidium compounds, the possibility of embedding strontium-90 through its precursor, rubidium-90, is even more remote, unless greater deviations from Raoult's law exist with rubidium than with strontium.

In the case of the Mass-90 chain, it has previously been shown that, at 100 seconds after fission, 10% of the chain is still in the form of krypton-90. Thus, in this case, a further requirement for control by embedding is that the matrix material be at a sufficiently high temperature to be above its melting point at times later than 100 seconds after detonation. As has also been shown previously, this is definitely not the case with shots smaller than 1 MT and is unlikely with shots in the 1- to 10-MT range.

In the case of an air burst, excluding the possibility of *external* addition of very large quantities of matrix material, materials introduced with the bomb would be restricted to the order of 1 ton/MT or less. Thus, as previously discussed, the particle size of any matrix material would be less than 1 micron, probably in the range 0.03 to 0.3 micron. With such fine particles, the question of solubility of a normally insoluble material over long periods of time, again arises as it did in the case of the borides previously discussed. In the case of matrix materials like silicates, however, the situation is somewhat better because of the depressive effect on solubility of siliceous materials already present in the soil.

With surface bursts, quantities of possible matrix material are tremendously greater than for an air burst. Consequently, equilibrium

vapor pressures are considerably lower, making dissolution of strontium-90 or rubidium-90 from the vapor phase many orders-of-magnitude more favorable in terms of Raoult's-law type considerations. Questions of long-term solubility are also of less importance, both because of the greater quantities of matrix material involved and because of the larger matrix particle sizes that are formed in the fireball-cloud.

In the case of a surface burst, the time-temperature history of the fireball, however, still constitutes a limiting factor. Here, as previously discussed in connection with  $\text{SrB}_6$ , a carbonaceous or organic matter substrate could be used to maintain high fireball temperatures artificially for longer periods of time. In this case, however, the prime purpose would be to increase the temperature rather than to provide a reducing atmosphere. Thus, some 100,000 tons of carbonaceous matter/MT would provide thermal energy equivalent to that of the total bomb energy. Such an addition of carbonaceous matter would require some 1.5 megatons of air/MT for complete combustion. This is almost ten times as much as is contained in the maximum-size fireball (see Table II). With so much carbon present it is possible that strontium would form the carbide, although this would probably revert to the respective oxides during later stages of combustion. Since the  $\text{SrC}_2$  is unstable (hydrolyzing in water to give off acetylene), this would be an undesirable end product unless it were contained in other carbides, such as  $\text{SiC}$ , which is highly refractory.

c. *Coating:* Instead of embedding strontium-90 or its precursors in a matrix of insoluble material, it might be possible to apply a coating of some impervious material. While it is conceivable that such coatings could be applied selectively to strontium-90-bearing particles, this is not likely, considering the improbability of finding a material having at the same time the proper combination of subsequently impervious character, proper physico-chemical property-temperature relationship, and selective affinity for strontium-90-bearing particles. It is likely, therefore, that the feasibility of any coating process must be predicated on coating all debris present in the fireball or cloud at the time of coating.

It is readily shown from geometrical considerations that the volume ratio of coating agent to total particulate matter to be coated is given by  $6 B/D_p$ , where  $B$  is the thickness of the coating to be applied

and  $D_p$  is the diameter of the particles to be coated. Thus, to apply a 0.1-micron thick shell around a 1-micron particle would require 60% by volume as much coating agent as particulate matter to be coated. To apply a 1-micron thick coating to a 100-micron particle would require 6% as much coating agent as particulate matter. Thus, as a first approximation, it may be concluded that any addition of coating agents must be made in quantities somewhat less than, but of the same order-of-magnitude as, the total amount of debris present at the time of coating. As will be discussed below, the various possible types of coating agents would involve additions of chemicals of reasonably high cost. The cost of such additions in quantities of the order of bomb debris would be nominal for an air burst. For a surface burst, however, the additions would involve a prohibitive cost. Thus coating can be considered as a possible control measure only for air bursts (or, possibly, bursts over deep water).

Being restricted to air bursts, the particle size of coated particles would be in the submicron range. Consequently, the question of the degree of protection offered by such thin coatings over long periods of time is also a possible limiting factor as in the case of embedding the particles.

Coatings might be applied either by additions to the bomb or by external additions to the fireball or cloud. Specific possible coating agents are discussed below.

(1) *Inorganic*: A material like silver or silver chloride might be added to the bomb or replace the bomb structure. If present in quantities corresponding to total bomb debris, silver metal would condense out at temperatures in the range of 1000 to 1500°K, depending on the exact concentration present (see Figure 5). Since the melting point is 1234°K, it could condense either as a liquid or as a solid. It would not form the oxide, which is unstable at elevated temperature. Silver chloride would condense in the range of 800 to 1000°K, which is above its melting point of 728°K. However, it is likely that any silver originally present as AgCl would condense out as the metal at these temperatures.

Since  $\text{Sr}^{90}\text{O}$  would condense to the solid at about 1500°K, it could serve as a nucleus for condensing silver. However, this would only happen if the Mass-90 chain were largely in the form of strontium-90 at that time. Thus, here again, the time-temperature history of the

fireball and cloud constitutes a major limiting factor. As previously indicated, it is likely that sufficient strontium-90 would form for the above mechanism to be feasible only with weapons larger than 10 MT.

(2) *Organic*: External addition of chemicals would permit the use of organics as coating agents. This, however, presents a formidable engineering problem of distributing the chemical in amounts of the order of 1 ton/MT over a fireball-cloud volume of some 1 cu mi/MT or greater. It would also be necessary to make the addition at some pre-determined time, in the range of 100 to 1000 seconds after fission.

Three general types of organic coating additions are conceivable: (1) volatile plastics (monomers or polymers); (2) volatile hydrocarbons; and (3) liquid plastic or hydrocarbon aerosols. The volatile plastic or hydrocarbon material might be added to the fireball-cloud at times when the temperature had dropped below some 700°K (to prevent decomposition), but was still high enough to vaporize the material. Subsequent cooling should then condense it on the bomb debris. In the case of monomers, subsequent exposure to air and light could serve as a means of polymerization. They might also be introduced as liquid aerosols to coat the strontium-90-bearing particles by a mechanical scavenging process.

In the case of the volatilized materials, quantities of the order of 1 ton/MT should be sufficient for an air burst, provided that they were added at the proper time. For the liquid aerosols, however, quantities would have to be sufficient to afford effective scavenging before the cloud became diluted to such an extent that atmospheric dust from the induced air became such a major constituent that the coating agent requirement became prohibitive. These quantities would also be dependent on the particle size of the organic aerosol. From Figure 9 it can be deduced that to scavenge 0.1-micron-diameter particles effectively with a 1-micron organic aerosol in a period of less than 1000 seconds would require on the order of 1000 tons/cu mi. Since this covers the period between the maximum-size fireball and rise-stabilized cloud, the organic aerosol requirement would be not less than 1,000 tons/MT and probably closer to 1,000,000 tons/MT. This would involve a prohibitive chemical cost.

If the organic aerosol consisted of 0.1-micron particles, the scavenging requirement would be less than 10,000 tons/MT. With an organic material like a lubricating oil, this would be economically

feasible. For a plastic, however, the chemical cost would still be prohibitive. It may be concluded, therefore, that aerosol additions would be restricted to relatively inexpensive materials and would require particles of the order of 0.1 micron. However, to make 0.1-micron particles would require aerosol generation by condensation techniques and hence would require a volatile hydrocarbon. Thus the only advantage of applying a coating in the form of a liquid aerosol, over applying it by direct condensation, is that it would extend the time interval over which the addition had to be made. From a practical standpoint, this means that excess amounts of volatile hydrocarbon would be applied at as early a time as temperature would permit, the excess serving as a subsequent aerosol scavenger to compensate for shortcomings in initial distribution of the organic matter.

When dealing with organic coatings, a further restriction must be imposed. The vapor pressure of the organic material at ambient temperatures must not exceed some  $10^{-10}$  mm Hg, assuming an initial addition of 10,000 tons; otherwise it would ultimately volatilize when the debris became mixed in the world's atmosphere. This requirement would eliminate most known liquid hydrocarbons.

In view of the above, it must be concluded that volatile plastics offer the only possibly feasible type of organic coating. As in the case of dye lakes, the question of long-period chemical stability arises.

### C. GENERAL CONSIDERATIONS

In the case of surface bursts, the surface debris will be several orders-of-magnitude greater than any bomb debris and will be mixed with the fireball cloud to a large extent at the time-period when control measures must be applied (later than 100 seconds after detonation) in order to be highly effective. It is consequently difficult to conceive of any additions to the bomb itself as providing an effective control measure in the case of a land surface burst, because of the overshadowing influence of the surface debris. Bomb additions could only be effective in such cases if the bomb material were concentrated in a discrete fraction of the fireball not penetrated by surface debris. As shown previously, the life of such a discrete volume, if it exists at all, should not be greater than some 10 seconds. It must, therefore, be concluded that direct bomb additions can be potentially effective only with air bursts (or possibly

bursts over deep water where the debris, NaCl, is smaller in amount and relatively more volatile).

In view of the above, the strontium-90 hazard from surface bursts must be dealt with by some form of substrate control. Several of the conceivable methods of control may be achieved by proper substrate selection or preparation. Each potential method calls for a different substrate specification. However, in most cases the specifications for the various control measures are not incompatible and may supplement each other. Mechanical scavenging, for example, calls primarily for a controlled particle size and maximum quantity of entrained surface debris, with little consideration of the chemical nature of the debris. Embedding in an insoluble matrix, on the other hand, places the emphasis on the chemical nature of the debris. However, the quantity and size control needed for mechanical scavenging also enhances the rate at which embedding takes place. Similarly, the addition of boric oxide to the substrate for the potential formation of  $\text{SrB}_6$  could also serve as a flux for lowering the melting point of substrate matrix material needed for embedding. The addition of any carbonaceous matter to provide a reducing atmosphere also serves to prolong the fireball temperature, which is desirable for embedding processes. Whereas such carbon addition may reduce the quantity of solid debris available for mechanical scavenging, it compensates for this by increasing the relative amounts of fission products scavenged by condensation on the surface debris. Thus an ultimate specification for substrate control may well involve a combination of specifications aimed at achieving control by a number of simultaneous mechanisms.

It should also be noted that, in a number of conceivable control mechanisms applicable to air bursts, the ultimate stability over long time-periods of very small particles constitutes an unresolved and possibly serious limitation.



---

C. E. LAPPLE  
Senior Scientist



## NOMENCLATURE

Units given below are in the c.g.s. system and are applicable to all equations or terms unless other units are specifically indicated in the text. Any other consistent set of absolute units may also be used in all equations for which no special units are specifically indicated in the text. Except where specifically noted otherwise, volume refers to actual volume, and *not* volume referred to some standard condition.

$a_{\bullet}$	= constant in Stokes-Cunningham correction, dimensionless
$A$	= area, sq cm
$A_b$	= area of scavenging or collector particle or body projected in plane normal to flow, sq cm
$A_c$	= area of cloud, sq cm
$A_p$	= area of particle projected in plane normal to flow, sq cm
$B$	= coating thickness, cm
$c$	= concentration, g/cu cm
$c_b$	= concentration of scavenging or collecting particles or bodies in atmosphere, g/cu cm
$c_{hp}$	= specific heat of gas at constant pressure, (g-cal)/(g)(°K)
$c_o$	= concentration of vapor in ambient atmosphere, g/cu cm
$c_p$	= concentration of particles in atmosphere, g/cu cm
$c_{p_o}$	= initial concentration of particles in atmosphere, g/cu cm
$c_s$	= concentration of vapor for saturation at particle surface temperature, g/cu cm
$d$	= "derivative of"
$D_b$	= scavenging or collector particle or body diameter, cm
$D_p$	= particle diameter, cm
$D_v$	= diffusion coefficient for vapor in atmosphere, cm <sup>2</sup> /sec
$D_{vp}$	= diffusion coefficient for suspended particles in atmosphere, cm <sup>2</sup> /sec = $k_{\bullet} RT/3\pi\mu N_A D_p$
$e$	= natural logarithmic base, 2.718...., dimensionless
$g_L$	= local acceleration due to gravity, 980.67 (cm)/(sec)(sec)



$H$	= cloud height, cm
$k_{\text{sc}}$	= Stokes-Cunningham correction factor, dimensionless
$K_e$	= equilibrium constant, various dimensions
$\ln$	= "logarithm to the base $e$ "
$m$	= mass in general; mass of radioactive element g
$m_f$	= mass of fireball (and/or cloud), g
$m_p$	= mass of particle suspended in atmosphere, g
$m_b$	= mass of scavenging or collector particle or body, g
$M$	= molecular weight, g/g mole
$M_b$	= total mass of scavenging or collector particles or bodies, g
$n$	= constant, dimensionless
$n_p$	= number concentration of suspended particles in atmosphere, particles/cu cm
$n_{p0}$	= initial number concentration of suspended particles in atmosphere, particles/cu cm
$n_{bc}$	= number concentration of scavenging or collector particles or bodies, particles/cu cm
$N_A$	= Avogadro's number = $6.02 \times 10^{23}$ molecules/g mole
$N_{Re}$	= Reynolds number, dimensionless = $D_b u_b \rho / \mu$
$N_{sd}$	= diffusional separation number = $D_{vp} / u_b D_b$ , dimensionless
$N_t$	= number of transfer units = $\ln[1/(1 - \eta)]$ , dimensionless
$p$	= partial pressure, dynes/sq cm
$P$	= total pressure, dynes/sq cm
$P_a$	= ambient pressure, dynes/sq cm
$q$	= volumetric flow rate, cu cm/sec
$Q_f$	= thermal energy delivered by nuclear weapon, g-cal
$R$	= gas constant = $8.314 \times 10^7$ (ergs)/(g mole)(°K)
$s_{vb}$	= specific projected surface, area of body projected on plane normal to direction of relative motion per unit body volume, 1/cm
$t$	= time, sec
$t_0$	= mean life of radioactive element, sec
$t_s$	= mean storage time in atmosphere, sec

$t_{1/2}$	= half-life of radioactive element, sec
$T$	= absolute temperature, °K
$T_a$	= absolute ambient temperature, °K
$T_f$	= absolute average fireball (and/or cloud) temperature, °K
$T_o$	= initial or reference temperature, °K
$u$	= velocity, cm/sec
$u_b$	= velocity of scavenging or collector particle or body relative to cloud, cm/sec
$u_t$	= terminal settling velocity of suspended particle under the action of gravity, cm/sec
$\bar{v}$	= mean molecular velocity = $\sqrt{8 RT/\pi M}$ , cm/sec
$V$	= volume, cu cm
$V_f$	= volume of fireball (and/or cloud), cu cm
$w$	= mass rate, g/sec
$w_p$	= mass deposition rate of particulates, g/sec
$w_t$	= rate of generation of radioactive element in weapons testing, g/sec
$Z$	= geopotential (substantially equal to height above sea level for levels below 200,000 ft), ft
$\rho$	= density of gas, g/cu cm
$\rho_p$	= density of particle, g/cu cm
$\rho_b$	= density of scavenging or collector particle or body, g/cu cm
$\mu$	= viscosity of gas, (g)/(cm)(sec)
$\lambda$	= mean free path of gas molecules = $3\mu/\rho\bar{v}$ , cm
$\eta$	= over-all collection efficiency; or fraction of component, dimensionless
$\eta_t$	= target efficiency, ratio of material collected to material present in gas volume swept out by particle, dimensionless
$\eta_{O_2}$	= volume fraction of oxygen in ambient atmosphere, dimensionless
$\beta$	= ratio of two quantities, dimensionless
$\sigma$	= standard geometric mean deviation



## ACKNOWLEDGMENT

This study was carried out by the staff of the Chemical Engineering and the Atmospheric Chemical Physics Sections of the Chemistry Department, with advisory service from the Physics Department. Technical liaison with the Atomic Energy Commission was maintained through H. N. Wellhauser and H. G. Curtis of the San Francisco Operations Office, Oakland, California.

Especial acknowledgment is extended to those who contributed of their time and effort in helpful discussion and criticism, or other assistance:

Air Force Cambridge Research Center

I. H. Blifford, Jr.

Atomic Energy Commission

New York Operations Office

J. H. Harley

S. Allan Lough

Washington Office

J. Z. Holland

J. C. Potts

Los Alamos Scientific Laboratory, Los Alamos, New Mexico

G. A. Cowan

Naval Radiological Defense Laboratory, San Francisco

C. E. Adams

N. E. Ballou

R. P. Day

R. W. Hillendahl

P. D. La Riviere

C. E. Miller

W. B. Plum

Library staff

University of California Radiation Laboratory, Livermore, California

R. E. Batzel

Dorothy Baughman

R. H. Goeckermann

K. E. Street

Library staff



## **FIGURES**



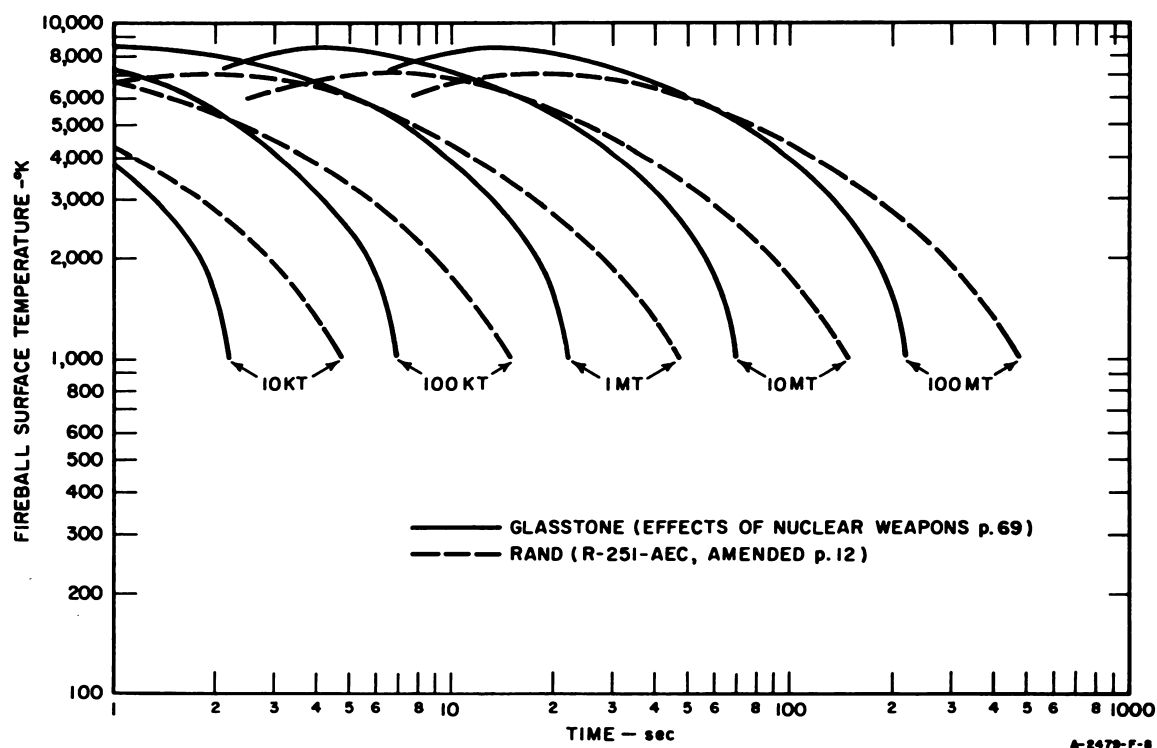


FIG. 2  
 SURFACE TEMPERATURE OF FIREBALL AS FUNCTION OF TIME AND YIELD



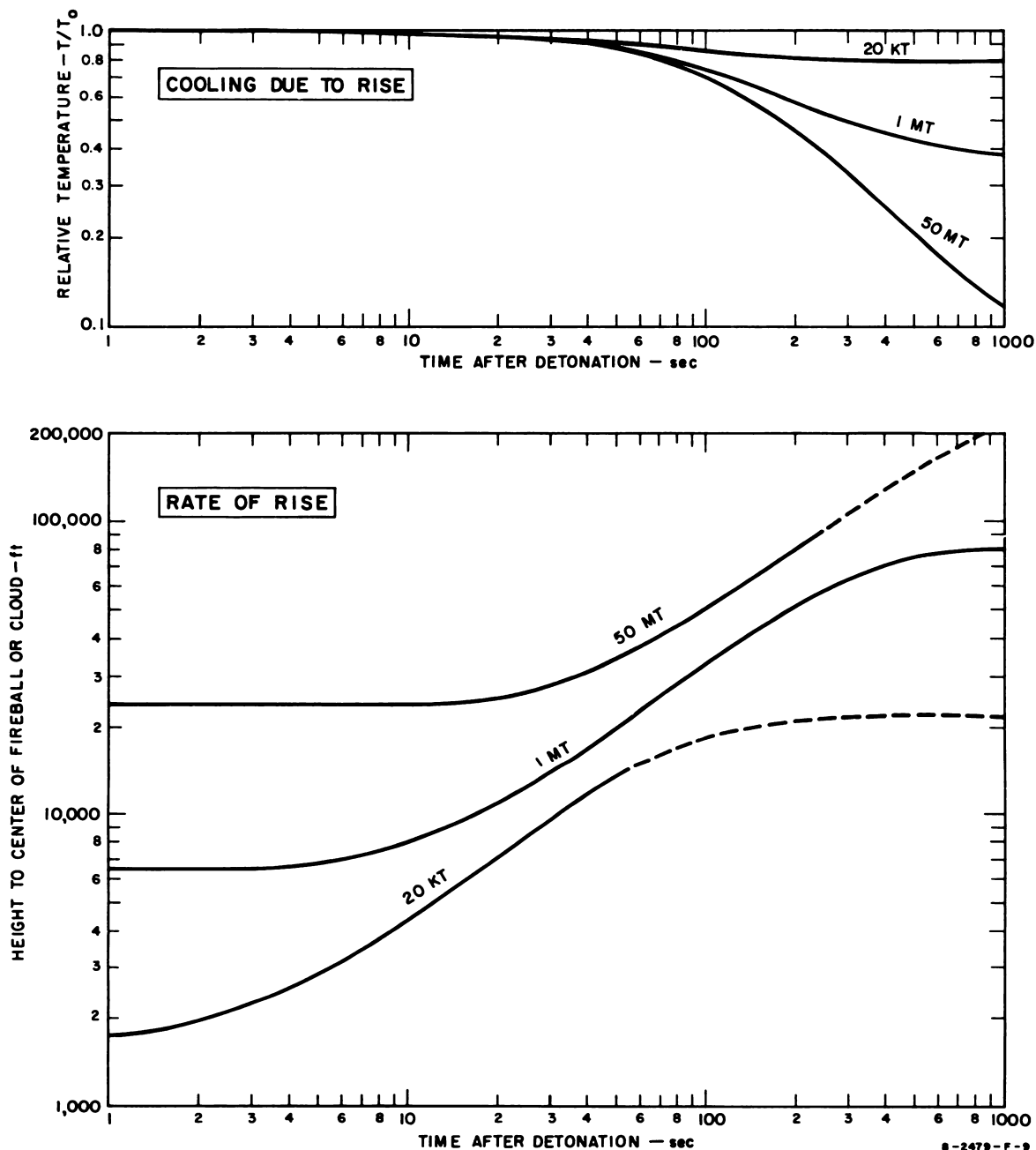


FIG. 3  
RISE OF FIREBALL AND CLOUD

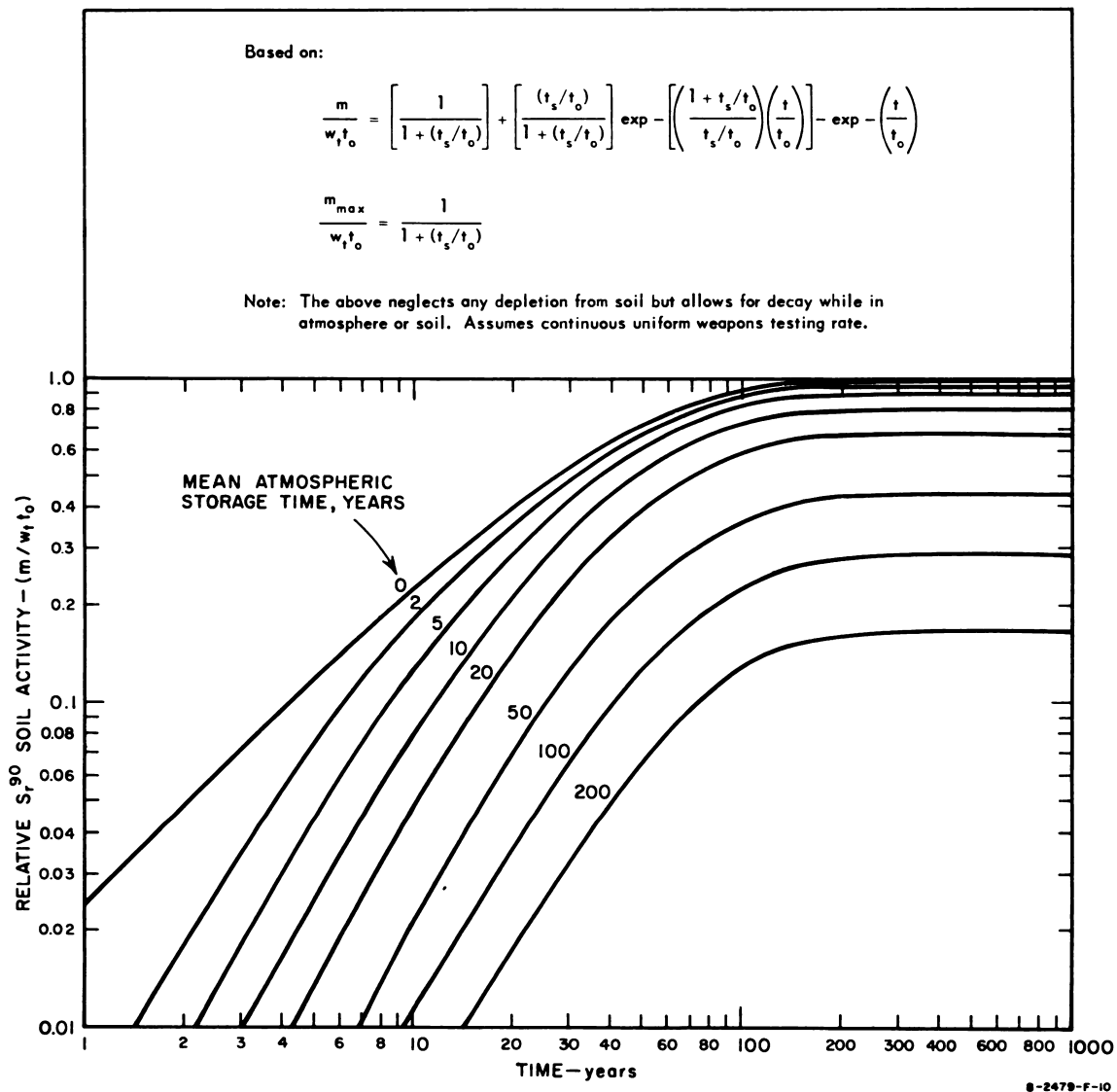


FIG. 4  
BUILDUP OF RADIOACTIVITY IN SOIL FROM STRATOSPHERIC FALLOUT

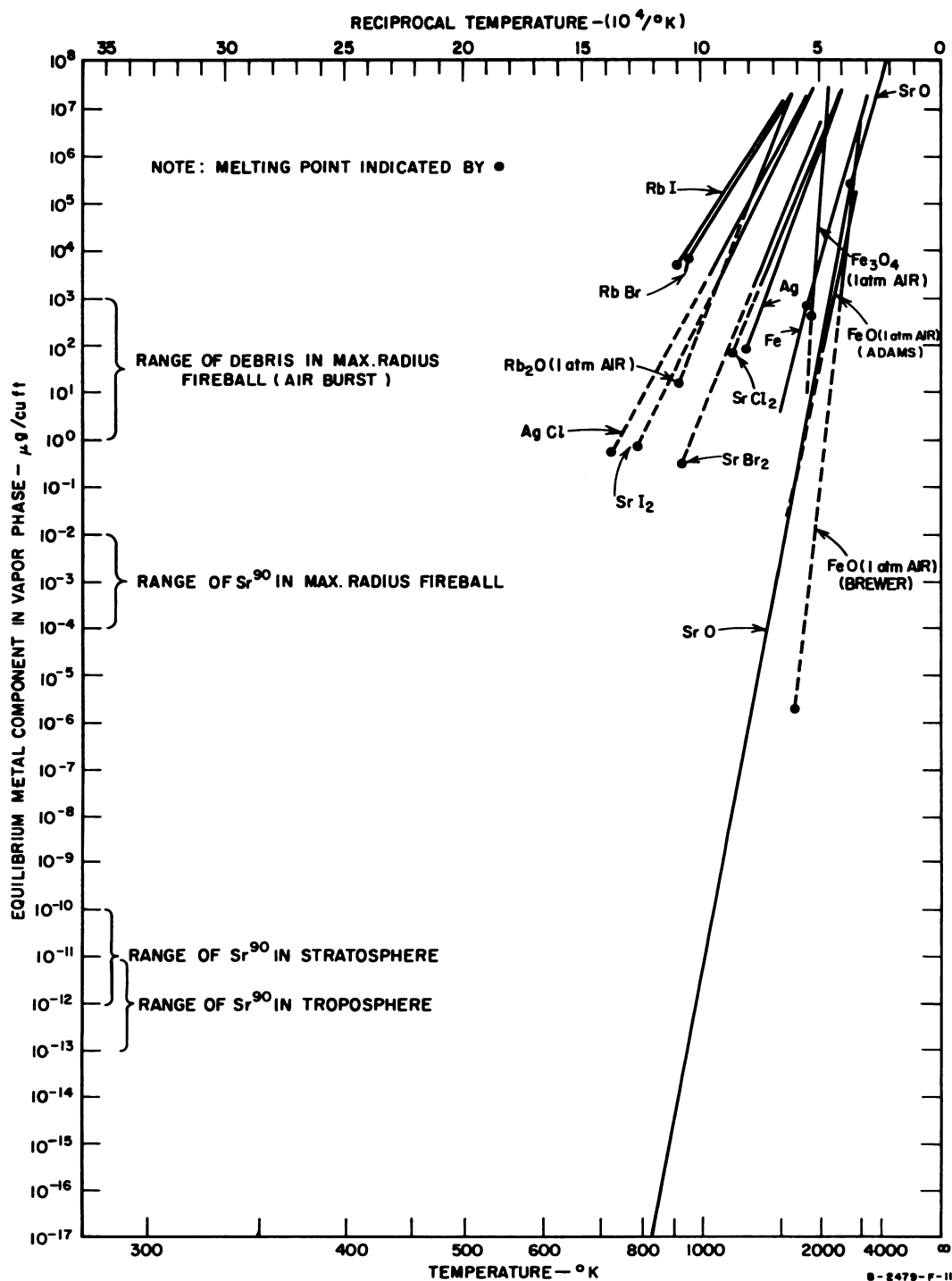


FIG. 5  
EQUILIBRIUM VAPOR PHASE CONTENT OF VARIOUS METALLIC COMPONENTS

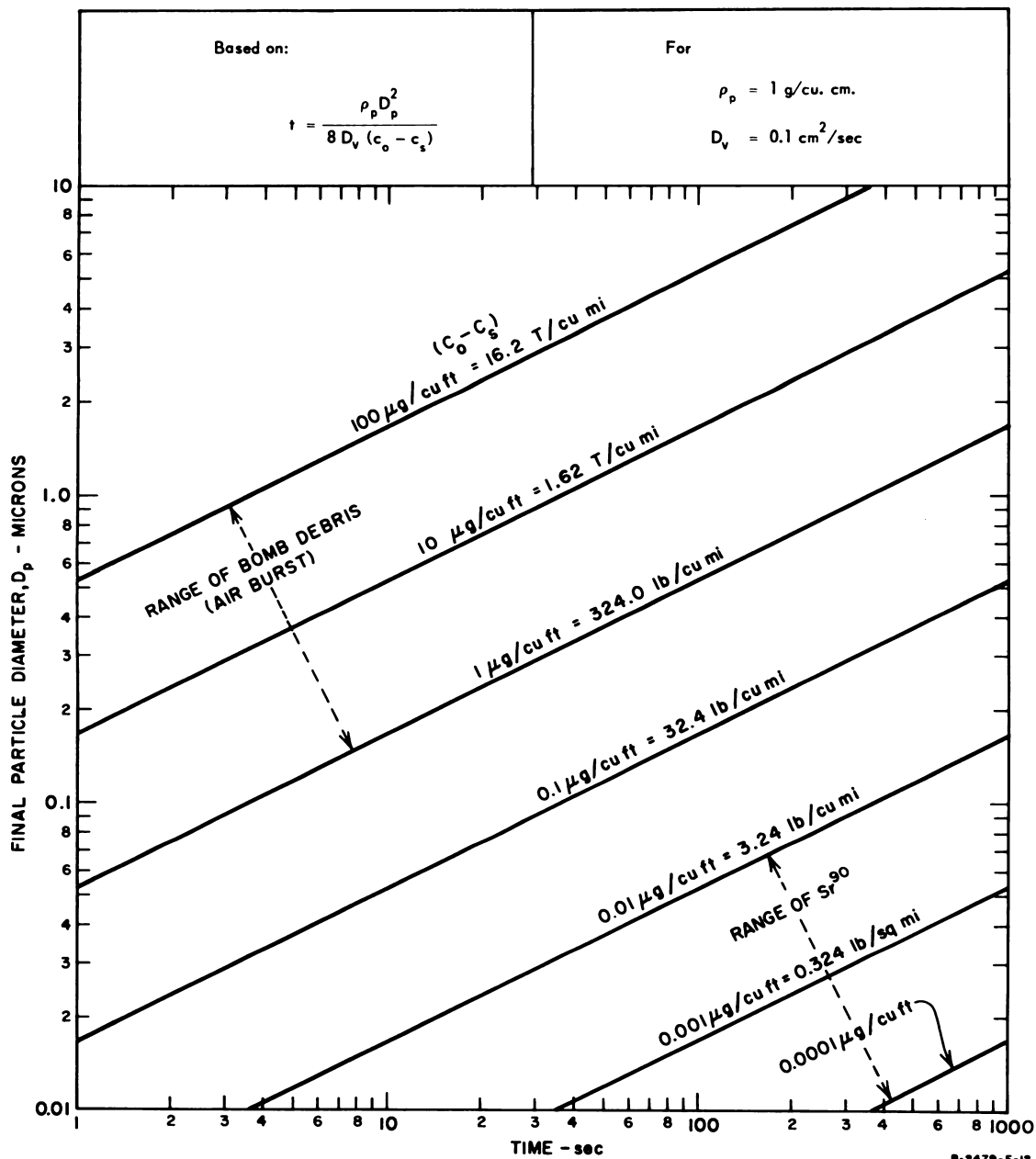


FIG. 6  
RATE OF PARTICLE GROWTH BY CONDENSATION

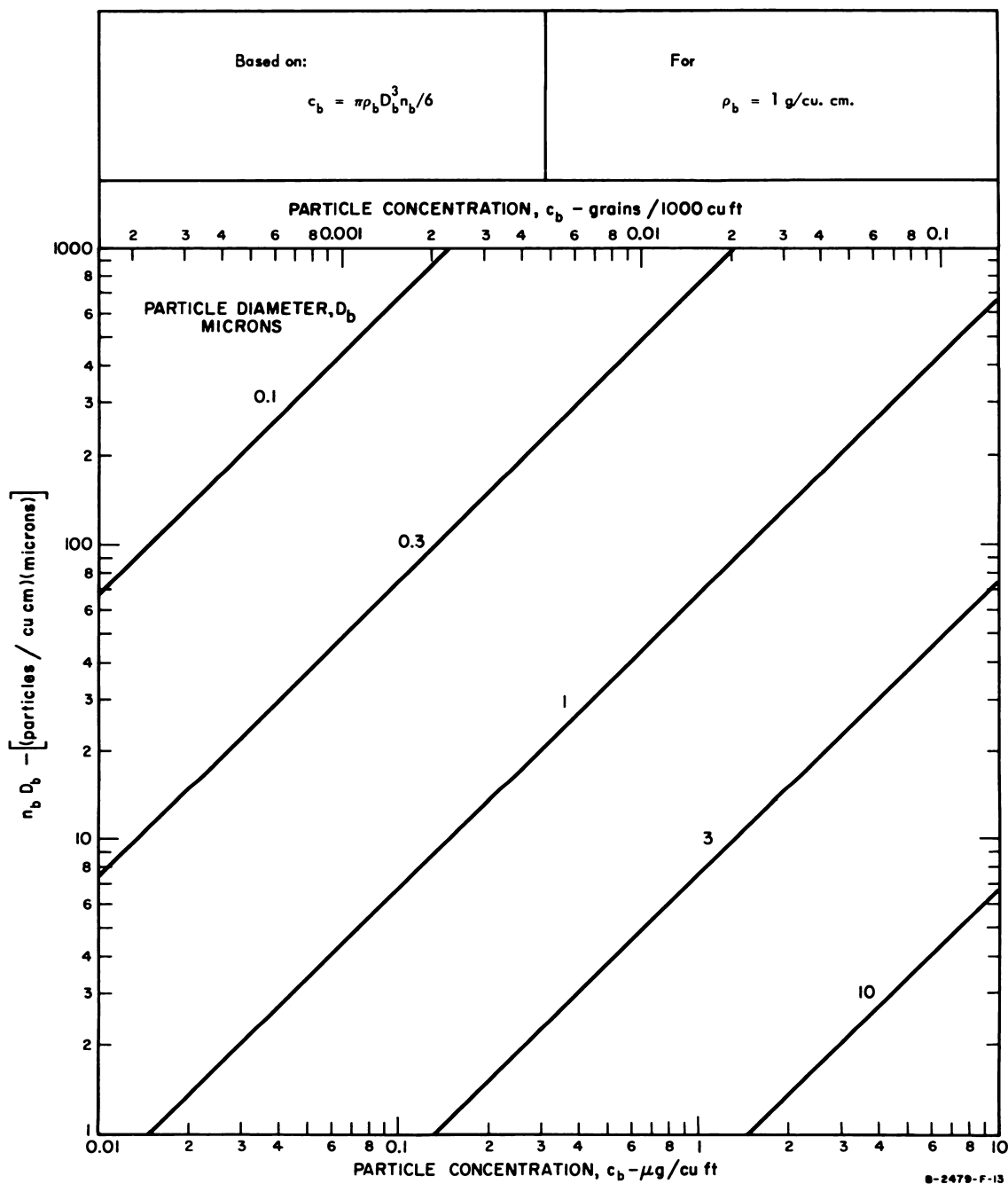


FIG. 7  
RELATIONSHIP BETWEEN  $n_b D_b$  AND PARTICLE CONCENTRATION AND SIZE

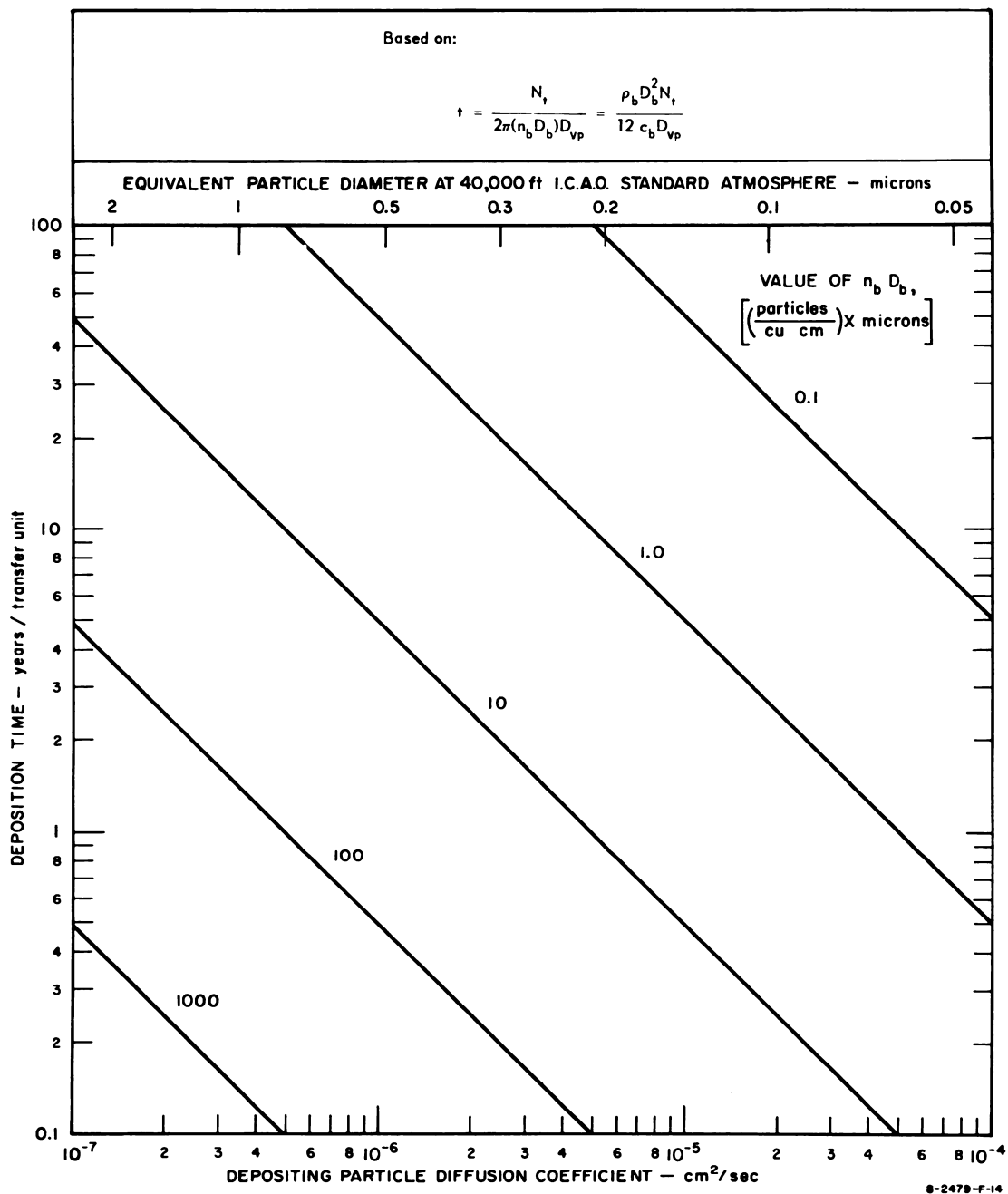


FIG. 8  
 DIFFUSIONAL SCAVENGING OF SMALL PARTICLES BY LARGER PARTICLES

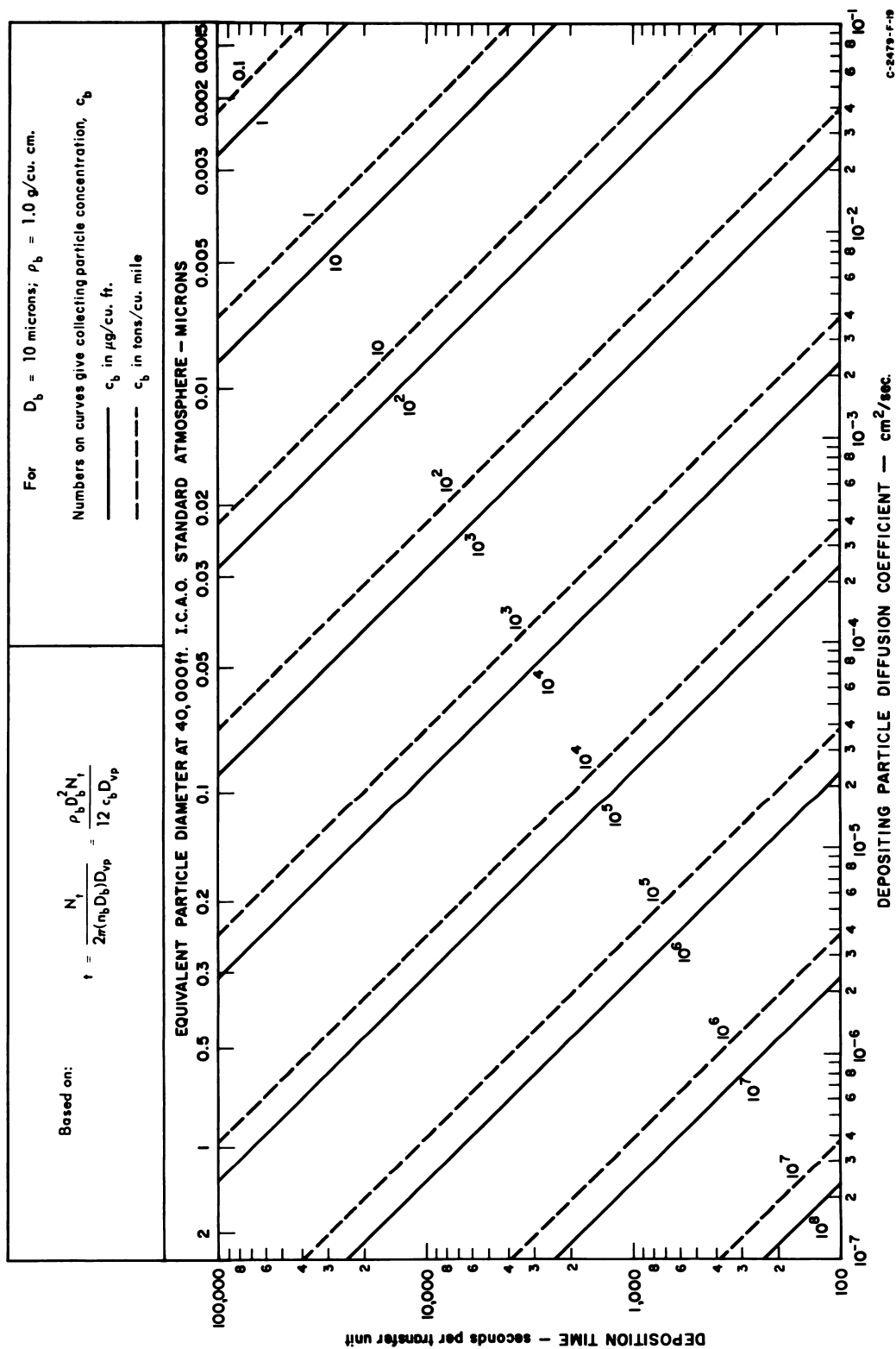


FIG. 9  
 DEPOSITION OF SMALL PARTICLES OR VAPORS ON SPHERICAL BODIES BY DIFFUSION IN QUIESCENT GAS

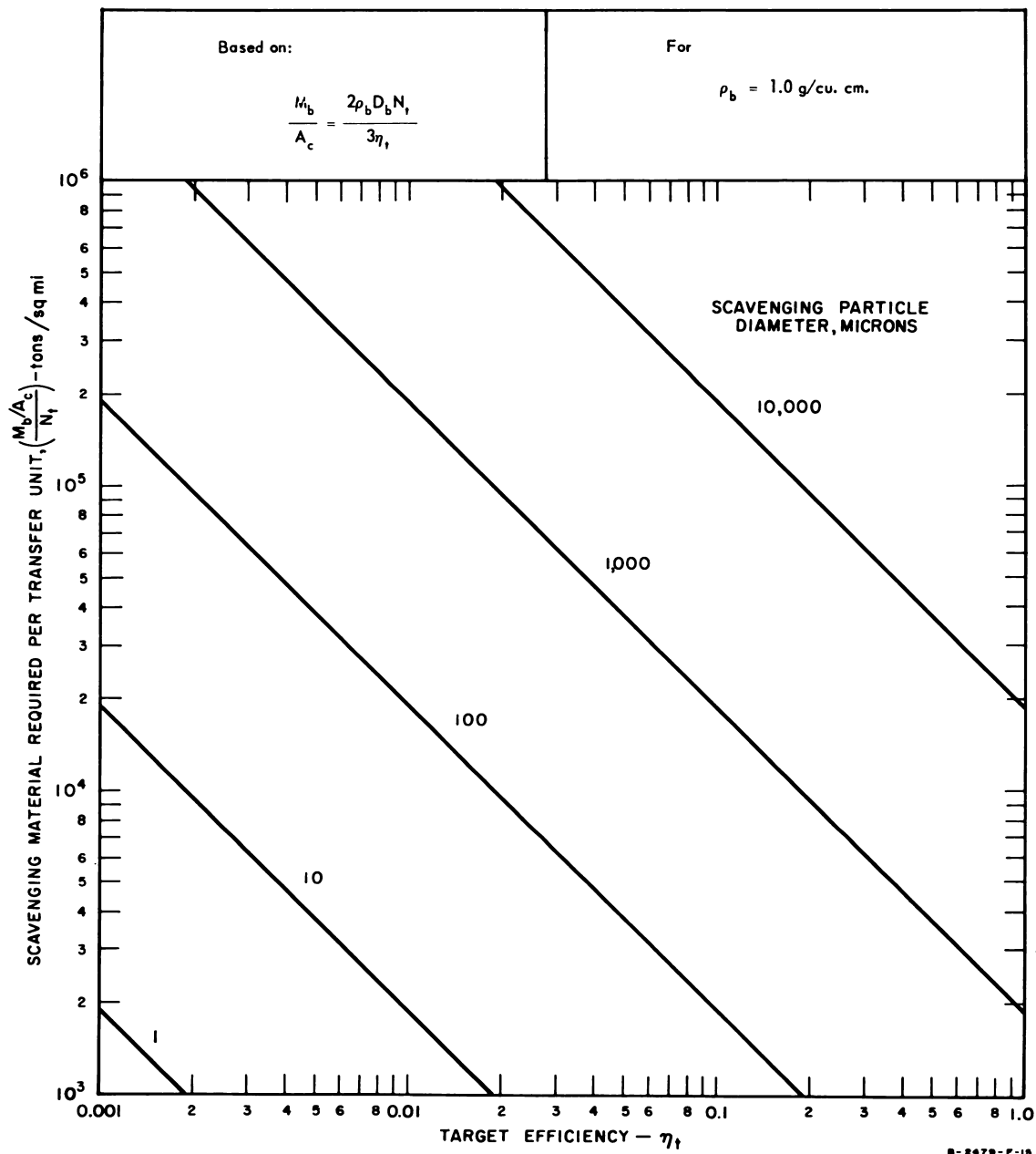


FIG. 10

SCAVENGING REQUIREMENTS AS A FUNCTION OF TARGET EFFICIENCY AND SCAVENGER PARTICLE SIZE





## **TABLES**



Table II  
FIREBALL CONDITIONS (AIR BURST)

WEAPON YIELD, TNT EQUIVALENT	MAXIMUM FIREBALL SIZE*.††							COMPONENT CONCENTRATIONS IN MAX FIREBALL µg/cu ft		TIME FOR SURFACE TEMP TO DROP TO 1000°Kil. †† seconds
	Diameter, ft	Area**		Volume		Air Mass‡		Bomb Debris†	Sr90§	
		sq mi (statute)	( $\frac{\text{sq mi}}{\text{MT}}$ )	cu mi (statute)	( $\frac{\text{cu mi}}{\text{MT}}$ )	tons	( $\frac{\text{megatons}}{\text{MT}}$ )			
1 KT	460	0.0060	6.0	0.00035	0.35	68	0.068	18	0.019	0.7
10 KT	1,150	0.037	3.7	0.0054	0.54	1,060	0.106	11	0.013	2.2
100 KT	2,900	0.24	2.4	0.088	0.88	17,000	0.17	7	0.008	7
1 MT	7,200	1.5	1.5	1.3	1.3	260,000	0.26	4.7	0.005	22
10 MT	18,400	10	1.0	22	2.2	4,300,000	0.43	2.8	0.0031	70
100 MT	46,000	60	0.6	350	3.5	68,000,000	0.68	1.8	0.0019	220

\* Basis: Diam., ft = 460 (KT)<sup>2/5</sup> [Glasstone (18), p. 66]

† On arbitrary basis of 1 T debris/MT

§ On basis of 1 g Sr90/KT

|| Basis: time, sec = 0.7 (KT)<sup>1/2</sup> [Glasstone (18), p. 69]

# Calc. arbitrarily on basis of 8300°K (second max. temp.) and 1 standard atm. pressure ( $\rho = 0.00266$  lb/cu ft). For small weapon yields, the actual value may be some few-fold higher because of lower actual temperature at time of maximum radius; for large yields, the actual value may be somewhat lower because of lower density resulting from altitude.

\*\* Horizontal projected area

†† Rand Corp. (47, p. 12) lists values for maximum fireball diameter which are 0.54 times those given by Glasstone and values of time for temperature to drop to 1000°K which are 2.1 times those given by Glasstone

Table III  
FIREBALL-CLOUD DIMENSIONS TEN MINUTES AFTER DETONATION\*

WEAPON YIELD, TNT EQUIVALENT	ELEVATION OF CLOUD		MUSHROOM HEAD PROPERTIES†						
	Bottom ft	Top ft	Diameter ft	Height ft	Area		Volume		Mass‡
					sq mi (statute)	(sq mi) MT	cu mi (statute)	(cu mi) MT	
1 KT	8,000	10,800	6,100	2,800	1.0	1,000	0.53	530	2,200
10 KT	23,000	28,500	15,200	5,500	6.5	650	6.8	680	1,650
100 KT	36,000	47,000	41,000	11,000	47	470	100	1,000	1,260
1 MT	47,000	69,000	110,000	22,000	340	340	1,400	1,400	820
10 MT	55,000	102,000	300,000	47,000	2,500	250	23,000	2,300	520
100 MT	70,000	170,000	790,000	100,000	17,600	176	330,000	3,300	99

\* Based on values reported by Schuert, E. A. ("A Fallout Forecasting Technique with Results Obtained at the Eniwetok Proving Ground," US NRDL-TR-139, April 3, 1957; also pp 282-3 of U.S. Congress, "Hearings on the Nature of Radioactive Fallout and Its Effects on Man," May 27-June 3, 1957). Values essentially identical to those reported by Kellogg, W. W. ("Atomic Cloud Height as a Function of Yield and Meteorology," AECU 3403, June 14, 1956).

† Vertical rise stabilizes in approximately 6 minutes, independent of yield. However, expansion of mushroom diameter continues for some 30 minutes for megaton devices.

§ Calculated on basis of ambient atmospheric density at average cloud elevation (see Appendix A for details of atmosphere).

Table IV  
SOLUBILITIES OF SOME ALKALINE EARTH COMPOUNDS  
Solubilities given in ppm by wt in water at 20°C

	Mg		Ca		Sr		Ba	
Boride	Mg <sub>3</sub> B <sub>2</sub>	--	CaB <sub>6</sub>	i	SrB <sub>6</sub>	i	BaB <sub>6</sub>	i
Carbonate	MgCO <sub>3</sub>	11	CaCO <sub>3</sub>	12	SrCO <sub>3</sub>	11	BaCO <sub>3</sub>	22
Chromate	MgCrO <sub>4</sub>	vs	CaCrO <sub>4</sub>	vs	SrCrO <sub>4</sub>	2,000	BaCrO <sub>4</sub>	4
Fluoride	MgF <sub>2</sub>	76	CaF <sub>2</sub>	16	SrF <sub>2</sub>	120	BaF <sub>2</sub>	1,600
Hydroxide	Mg(OH) <sub>2</sub>	9	Ca(OH) <sub>2</sub>	2,000	Sr(OH) <sub>2</sub>	10,000	Ba(OH) <sub>2</sub>	43,000
Silicate	MgSiO <sub>3</sub>	--	CaSiO <sub>3</sub>	95	SrSiO <sub>3</sub>	ss	BaSiO <sub>3</sub>	s
Sulfate	MgSO <sub>4</sub>	vs	CaSO <sub>4</sub>	2,980	SrSO <sub>4</sub>	113	BaSO <sub>4</sub>	2

i - insoluble; these borides are probably extremely insoluble

vs - very soluble (probably means >100,000 ppm)

s - soluble (probably means ~20,000 ppm)

ss - slightly soluble (probably means ~5,000 ppm)

The chromates and the sulfates decrease in solubility with increasing atomic weights

The nitrides, carbides, oxides, sulfides, and silicides of the alkaline earth metals are all easily hydrolysed

Data from:

Seidell, A. Solubilities of Inorganic and Metal Organic Compounds, Vol. 1, 3rd ed, 3rd printing. D. Van Nostrand Co., Inc., New York (1940)

Lange, N. A. Handbook of Chemistry, 9th ed. Handbook Publishers, Inc., Sandusky, Ohio (1956)

Mellor, J. W. A Comprehensive Treatise on Inorganic and Theoretical Chemistry, Vol. V. Longmans, Green & Co., Ltd. (1946) (for borides)

Table V  
RELATIONSHIP BETWEEN TRANSFER UNITS AND COLLECTION EFFICIENCY

$$N_t = \ln \left( \frac{1}{1 - \eta} \right)$$

when

$N_t$  = transfer units

$\eta$  = fractional efficiency of removal, deposition,  
or scavenging

Typical Values:

$N_t$	$\eta$ %
0.1	9.5
0.5	39.4
1.0	63.2
2.0	86.5
3	95.0
4	98.2
6	99.75
10	99.995

Table VI  
REFERENCE DATA AND CONVERSION FACTORS

<u>Dimensions of Earth:</u>	Equatorial Diameter = 7926 miles (statute)
	Polar Diameter = 7900 miles
	Area: Ocean = $1.395 \times 10^8$ sq mi
	Land = $0.575 \times 10^8$ sq mi
	Total = $1.97 \times 10^8$ sq mi = $5.50 \times 10^{15}$ sq ft
<u>Earth's Atmosphere:</u>	Total mass = $5.70 \times 10^{15}$ tons = $51.7 \times 10^{20}$ g = 51.7 Gg
	Volume (for 100,000 ft height) = $5.50 \times 10^{20}$ cu ft
	= $3.73 \times 10^9$ cu mi

Conversion Factors:

A. Radioactive

1 curie (c) = $3.7 \times 10^{10}$ disintegrations/sec
1 $\mu\text{c}$ = 2.22 dpm
1 Sunshine Unit (SU) = 1 $\mu\text{c}$ Sr <sup>90</sup> /g Ca
1 MPC = 1 $\mu\text{c}$ Sr <sup>90</sup> for standard man (corresponds approx. to 1000 SU)
1 g Sr <sup>89</sup> $\approx$ 27,000 curies $\approx$ $6.00 \times 10^{16}$ disintegrations/min
1 g Sr <sup>90</sup> $\approx$ 142 curies $\approx$ $3.15 \times 10^{14}$ disintegrations/min
1 g Cs <sup>137</sup> $\approx$ 98 curies $\approx$ $2.17 \times 10^{14}$ disintegrations/min
1 disintegration/min $\approx$ $3.17 \times 10^{-3}$ $\mu\text{g}$ Sr <sup>90</sup> $\approx$ $4.60 \times 10^{-3}$ $\mu\text{g}$ Cs <sup>137</sup>
$\approx$ $1.67 \times 10^{-5}$ $\mu\text{g}$ Sr <sup>89</sup>

B. Physical

1 $\mu\text{g}/\text{cu ft}$ = $3.53 \times 10^{-5}$ $\mu\text{g}/\text{cu cm}$ = 0.162 tons/cu mi = 0.0154 grains/1000 cu ft
1 year = 365 d = $5.25 \times 10^5$ min = $3.15 \times 10^7$ sec
1 mile = 5,280 ft = 1.61 km
1 square mile = $2.79 \times 10^7$ sq ft = 2.59 sq km
1 cubic mile = $1.47 \times 10^{11}$ cu ft = 4.17 cu km

Nominal Characteristics of Nuclear Weapons [per megaton (MT) yield]

Total energy liberated = $1 \times 10^{15}$ g-cal = $4 \times 10^{12}$ Btu
Thermal energy radiated = $3.3 \times 10^{14}$ g-cal = $1.3 \times 10^{12}$ Btu
Sr <sup>90</sup> production = 1000 g = 142,000 c
Bomb debris: 1 ton (varies widely)
Total debris (surface burst): 20,000 tons (varies widely)

Worldwide Sr<sup>90</sup> Distribution [on basis of 1000 g Sr<sup>90</sup> (or approx. 1 MT)]

A. Equivalent Concentration in Atmosphere (uniform distribution over 100,000-ft height):  
(volumes are actual, not volumes referred to standard conditions)

= $6.43 \times 10^{-5}$ $\mu\text{g}/\text{cu m}$ = $0.91 \times 10^{-2}$ $\mu\text{c}/\text{cu m}$ = $2.0 \times 10^{-2}$ dpm/cu m
= $6.43 \times 10^{-11}$ $\mu\text{g}/\text{cu cm}$ = $0.91 \times 10^{-8}$ $\mu\text{c}/\text{cu cm}$ = $2.0 \times 10^{-8}$ dpm/cu cm
= $1.82 \times 10^{-6}$ $\mu\text{g}/\text{cu ft}$ = $2.6 \times 10^{-4}$ $\mu\text{c}/\text{cu ft}$ = $5.7 \times 10^{-4}$ dpm/cu ft
= $2.95 \times 10^{-13}$ tons/cu mi = $3.8 \times 10^7$ $\mu\text{c}/\text{cu mi}$ = $8.4 \times 10^7$ dpm/cu mi

B. Equivalent Concentration on Earth's Surface (uniform distribution over land and water):

= 5.07 $\mu\text{g}/\text{sq mi}$ = 720 $\mu\text{c}/\text{sq mi}$ = 0.72 mc/sq mi = $1.60 \times 10^9$ dpm/sq mi
= 0.182 $\mu\text{g}/\text{sq ft}$ = 26 $\mu\text{c}/\text{sq ft}$ = 57 dpm/sq ft



*APPENDIX A*

**TERMINAL SETTLING VELOCITIES AND DIFFUSION COEFFICIENTS  
FOR AEROSOL PARTICLES**





## APPENDIX A

### TERMINAL SETTLING VELOCITIES AND DIFFUSION COEFFICIENTS FOR AEROSOL PARTICLES

#### I. TERMINAL SETTLING VELOCITIES

The terminal settling velocities of particles were calculated from Stokes' law with the Cunningham correction factor applied to allow for the effect of the mean free path of the air molecules on the motion of particles.<sup>46</sup>

$$u_t = \frac{k_c g_L (\rho_p - \rho) D_p^2}{18\mu} . \quad (\text{A-1})$$

The Cunningham correction factor,  $k_c$ , was calculated from

$$k_c = 1 + a_c \left( \frac{\lambda}{D_p} \right) , \quad (\text{A-2})$$

where

$$a_c = 1.644 + 0.522 e^{-[0.656 / (\lambda / D_p)]} . \quad (\text{A-3})$$

The mean free path of the air,  $\lambda$ , was calculated from

$$\lambda = \frac{3\mu}{\rho \bar{v}} . \quad (\text{A-4})$$

This is the value of the mean free path based on simple kinetic theory and is consistent with the constants given in Equation (A-3).

The average molecular velocity was calculated from

$$\bar{v} = \sqrt{\frac{8RT}{\pi M}} . \quad (\text{A-5})$$

Particles were assumed to be spherical and to have a specific gravity of 1.0. In Equation (A-1), the density of the air,  $\rho$ , was negligible compared to  $\rho_p$ , and was neglected in the calculation.

## II. DIFFUSION COEFFICIENTS

The diffusion coefficient for particles was calculated from

$$D_{vp} = \frac{k_a RT}{3\pi\mu N_A D_p} \quad (A-6)$$

## III. ATMOSPHERIC DATA

Atmospheric data were based on the International Civil Aviation Organization Standard Atmosphere.<sup>1021,1080</sup> From these were obtained the pressure, temperature, density, and viscosity of the air as functions of the altitude. These quantities are tabulated in Table A-I. The variation of temperature, pressure, and mean free path with altitude is shown graphically in Figures A-1 and A-2.

## IV. PRESENTATION OF DERIVED DATA

Terminal settling velocities and diffusion coefficients at a number of altitudes were calculated for particles having diameters of 0.01, 0.1, 1.0, and 10 microns. The results have been presented in two ways: (1) as absolute values (Fig. A-5 and A-6), and (2) as relative values (Fig. A-3 and A-4), taken relative to the value at sea level.

Table A-I  
PROPERTIES OF THE ICAO STANDARD ATMOSPHERE AS A FUNCTION OF ALTITUDE

ALTITUDE ABOVE SEA LEVEL, ft	TEMPERATURE			PRESSURE, mm Hg	RELATIVE DENSITY, $\left(\frac{\text{lb/cu ft}}{0.07648}\right)$	VISCOSITY, cps	MEAN FREE PATH, microns
	°F	°R	°K				
0	59.0	518.7	288.2	760.0	1.0000	0.01793	0.0954
500	57.2	516.9	287.2	746.3	0.9854	0.01788	0.0972
1,000	55.4	515.1	286.2	733.0	0.9710	0.01783	0.0981
5,000	41.2	500.9	278.3	632.5	0.8617	0.01744	0.110
10,000	23.3	483.0	268.3	522.7	0.7385	0.01693	0.127
15,000	5.5	465.2	258.4	429.0	0.6292	0.01643	0.147
20,000	-12.3	447.4	248.6	349.3	0.5328	0.01591	0.172
30,000	-48.0	411.7	228.7	225.7	0.3741	0.01484	0.238
36,089	-69.7	390.0	216.7	169.7	0.2971	0.01417	0.295
40,000	-69.7	390.0	216.7	140.7	0.2462	0.01417	0.357
50,000	-69.7	390.0	216.7	87.0	0.1522	0.01417	0.576
60,000	-69.7	390.0	216.7	53.8	0.0941	0.01417	0.933
70,000	-69.7	390.0	216.7	33.3	0.0582	0.01417	1.51
80,000	-69.7	390.0	216.7	20.7	0.0362	0.01417	2.42
90,000	-57.0	402.7	223.7	13.0	0.0220	0.01457	3.99
100,000	-40.7	419.0	232.8	8.18	0.0133	0.01506	6.58
120,000	- 8.3	451.4	250.8	3.45	0.00522	0.01603	16.8
140,000	24.5	484.2	269.0	1.57	0.00222	0.01696	39.3
160,000	49.3	509.0	282.8	0.757	0.00101	0.01766	86.6

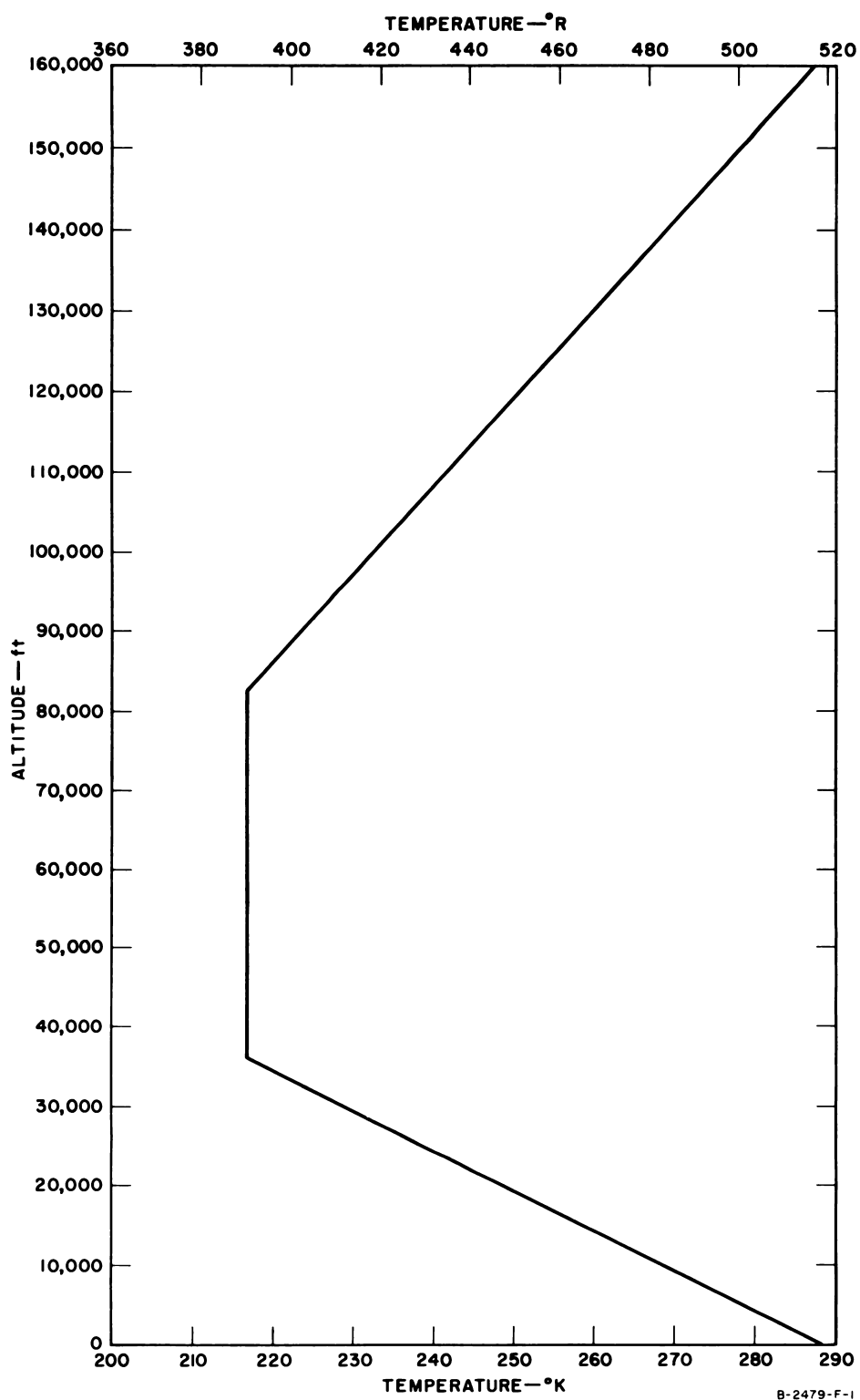
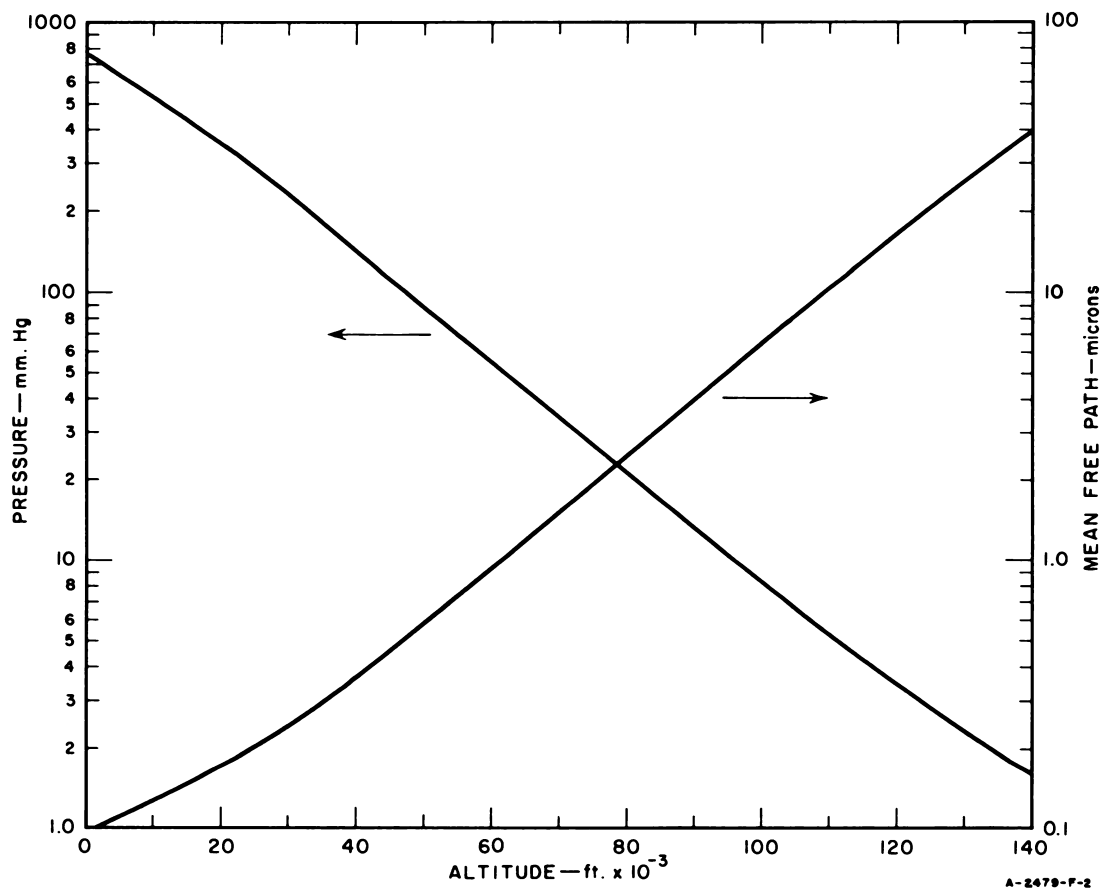
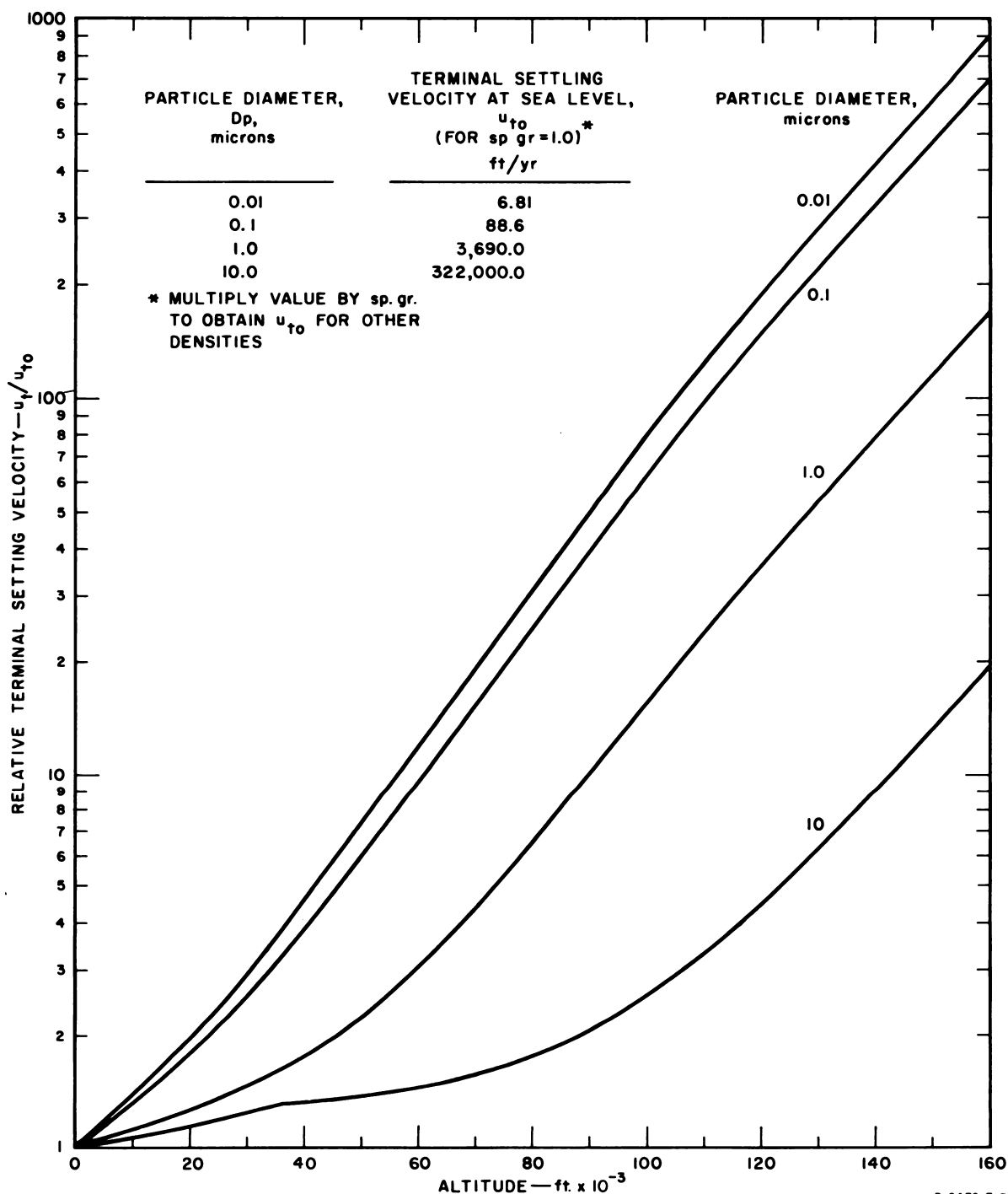


FIG. A-1  
VARIATION OF TEMPERATURE WITH ALTITUDE



**FIG. A-2**  
**VARIATION OF PRESSURE AND MEAN FREE PATH WITH ALTITUDE**



B-2479-F-3

FIG. A-3  
RELATIVE VARIATION OF SETTLING VELOCITY WITH ALTITUDE AND PARTICLE SIZE

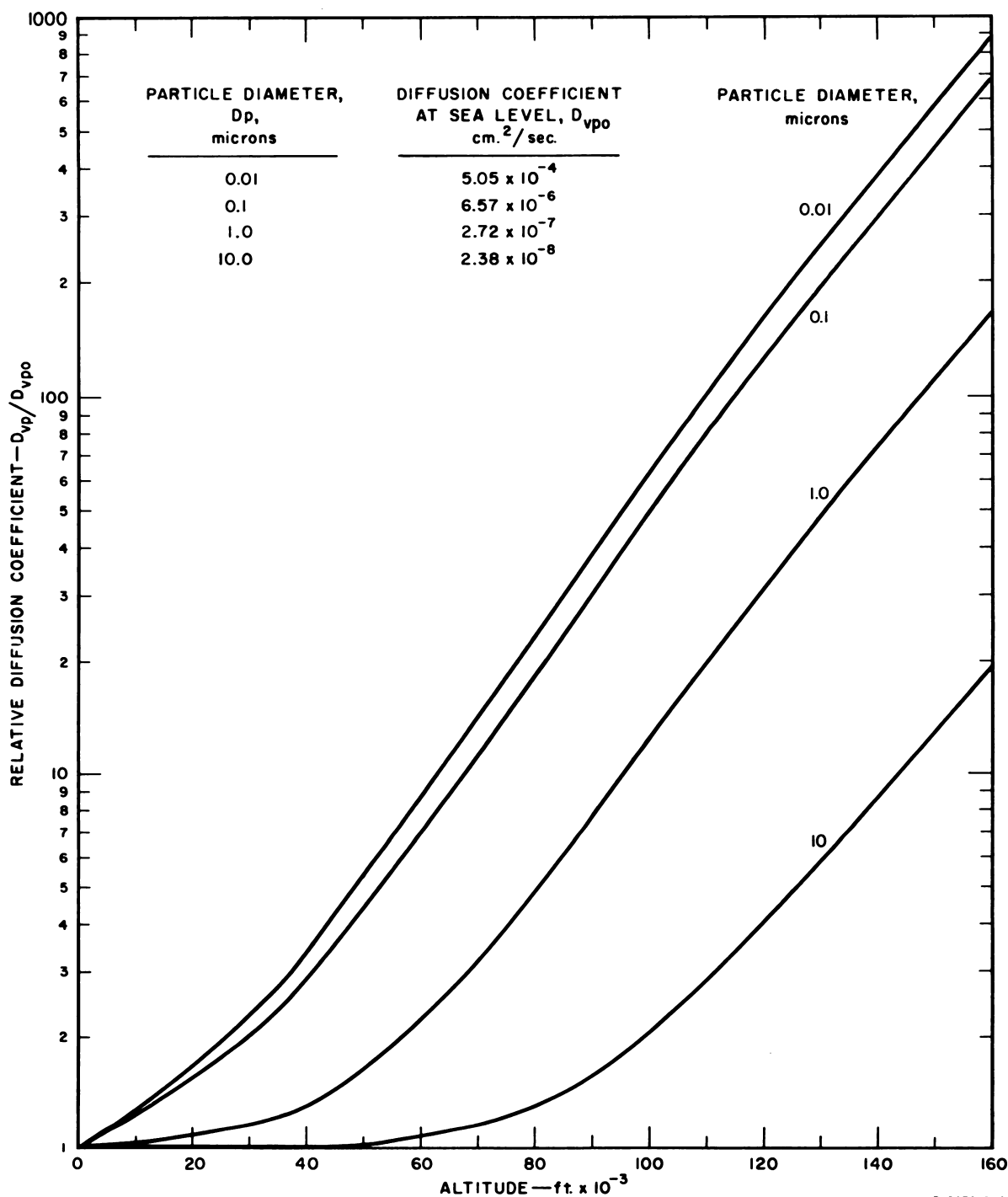
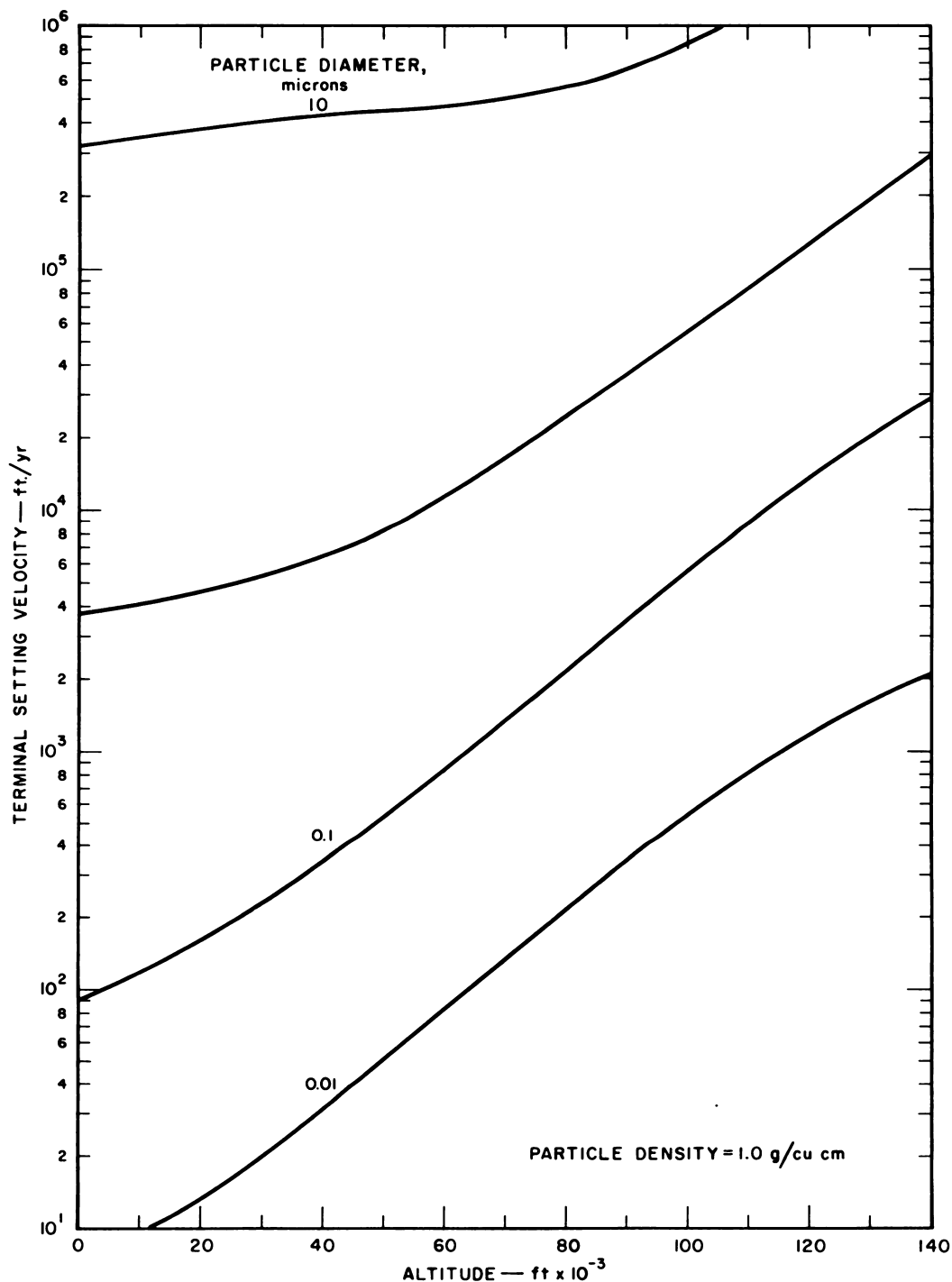


FIG. A-4

RELATIVE VARIATION OF DIFFUSION COEFFICIENT WITH ALTITUDE AND PARTICLE SIZE





B-2479-F-5

**FIG. A-5**  
**VARIATION OF SETTLING VELOCITY WITH ALTITUDE AND**  
**PARTICLE SIZE**

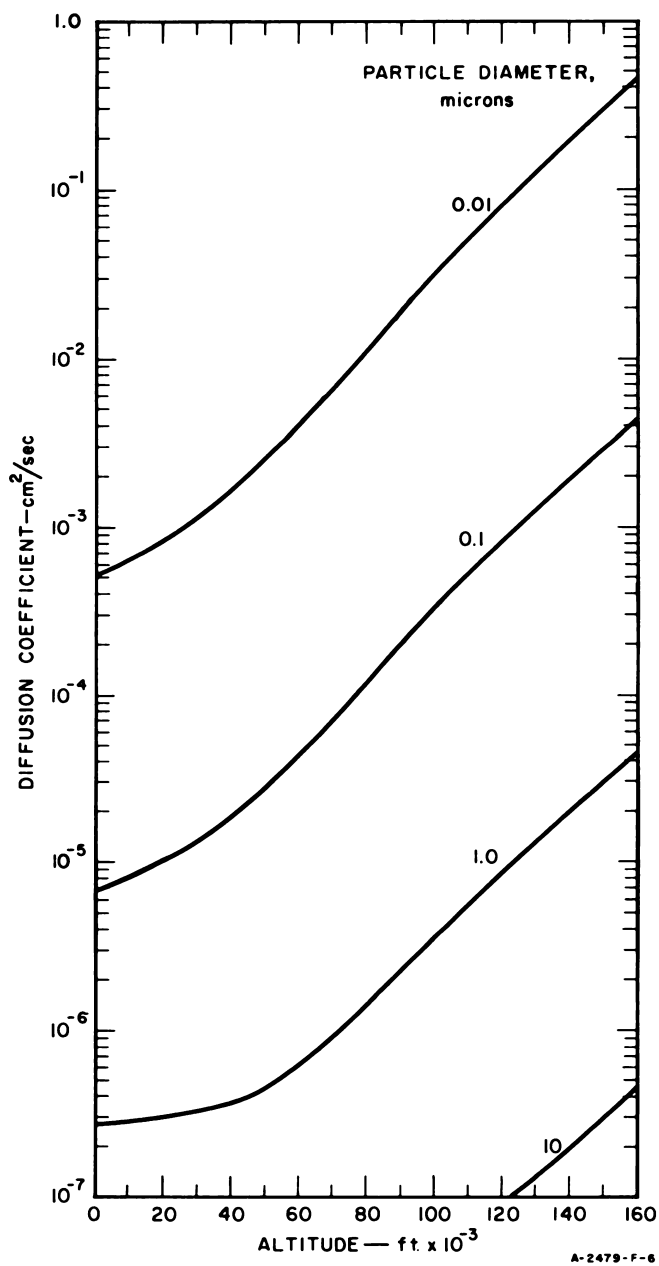


FIG. A-6  
VARIATION OF DIFFUSION COEFFICIENT WITH ALTITUDE AND  
PARTICLE SIZE



*APPENDIX B*

**VAPOR PRESSURE AND MELTING POINTS**



## APPENDIX B

### VAPOR PRESSURE AND MELTING POINTS

Table B-I summarizes melting points and vapor pressures for various compounds.

Some of the oxides dissociate upon vaporizing as given by:

$2M_{n/2}O(l, s) \rightleftharpoons nM(g) + O_2(g)$ . For such oxides the vapor pressure of the metal over the oxide, in general, depends both on the total pressure and on the oxygen content of the ambient atmosphere. If we assume that the equilibrium constant,  $K_e$ , is a function of temperature only, we may write

$$K_e = (p_M)^n (p_{O_2}) = p_M^n \left\{ \left[ P - \left( \frac{1+n}{n} \right) p_M \right] \eta_{O_2} + \left( \frac{p_M}{n} \right) \right\} = \frac{p_{Mi}^{n+1}}{n},$$

where

$p_M$  = partial pressure of  $M$  in atmosphere of total pressure  $P$ , composition  $\eta_{O_2}$ , and temperature  $T$

$p_{Mi}$  = partial pressure of  $M$  in inert atmosphere at temperature  $T$

$\eta_{O_2}$  = volume fraction of  $O_2$  in ambient atmosphere.

From this we may write, for a given temperature,

$$p_{Mi} = p_M^{[n/(1+n)]} \left[ n\eta_{O_2} P + p_M (1 - \eta_{O_2} - n\eta_{O_2}) \right]^{[1/(1+n)]},$$

which gives the relationship between partial pressure in an inert atmosphere and the partial pressure in another atmosphere at the same temperature. For oxides vaporizing into standard atmospheric air:

$P = 1 \text{ atm}; \eta_{O_2} = 0.21$ .

For  $Rb_2O$ :  $n = 4$

$$p_{Mi} = p_M^{4/5} (0.84 - 0.05 p_M)^{1/5} \quad \text{for } p_M \leq 4/5 \text{ atm}$$

For FeO:  $n = 2$

$$p_{Mi} = p_M^{2/3} (0.42 + 0.37 p_M)^{1/3} \quad \text{for } p_M \leq 2/3 \text{ atm}$$

For Fe<sub>3</sub>O<sub>4</sub>:  $n = 3/2$

$$p_{Mi} = p_M^{3/5} (0.315 + 0.475 p_M)^{2/5} \quad \text{for } p_M \leq 3/5 \text{ atm}$$

where  $p_M$  and  $p_{Mi}$  are expressed in atmospheres. The upper limitation on  $p_M$  corresponds to the condition where the total pressure of dissociation of the oxide is one atmosphere (in other words, the oxide is at its "boiling point," and  $p_M = p_{Mi}$ ).

For assessment convenience, the vapor pressure may be expressed in terms of concentration, which is related to vapor pressure by

$$c, \mu\text{g/cu ft} = 3.46 \times 10^8 M(p, \text{ atm})/(T, ^\circ\text{K})$$

where  $M$  is the molecular weight of the vapor molecule. Various of the equilibrium metallic concentrations are shown as a function of temperature in Figure 5. In preparing these curves, the metallic component was assumed as monatomic in the vapor phase in all cases. In the case of Rb and Sr,  $M$  has been taken as 90 to be consistent with the radioactive element. For the oxides which dissociate (Rb<sub>2</sub>O, FeO, Fe<sub>3</sub>O<sub>4</sub>), curves are given for equilibrium with air at a total pressure of 1 atmosphere; hence the top ends of these curves stop at the point where the equilibrium composition is 1 atmosphere of the oxide. In the case of FeO, two curves are given, one based on the values calculated by Adams,<sup>1024</sup> and another based on calculations from data reported by Brewer.<sup>1035</sup>

It was noted over the range considered that plotting vapor pressure in terms of logarithm of vapor density (or  $\mu\text{g/cu ft}$ ) against reciprocal temperature (as is done in Figure 5) results in straight lines. In cases involving a phase change from liquid to solid, two straight lines of different slopes resulted. While the Clausius-Clapeyron relationship would predict this for vapor pressure, the conversion of vapor pressure to units of vapor density involves an additional temperature term. The practical effect of this additional temperature term is apparently to simply change the slope rather than the shape of the vapor pressure curve.

**Table B-I**  
**SUMMARY OF VAPOR PRESSURE DATA AND MELTING POINTS\***

Substance	Melting Point °K	Temperature, "K°										Reference Source for Melting Point	Reference Source for Vapor Pressure
		Vapor Pressure in Atmospheres											
		10 <sup>-18</sup>	10 <sup>-15</sup>	10 <sup>-12</sup>	10 <sup>-9</sup>	10 <sup>-6</sup>	10 <sup>-5</sup>	10 <sup>-4</sup>	10 <sup>-3</sup>	10 <sup>-2</sup>	1		
Rb	312					403(ℓ)	445	496	561	650	952	e, g	g
Cs	302					383(ℓ)	425	476	544	634	963	e, g	g
Ca	1123, 1124					790(s)	867	961	1075	1231(ℓ)	1755	e, g	g
Sr	1043, 1044					740(s)	810	900	1010	1150(ℓ)	1657	e, g	g
Ba	977, 990					810(s)	890	985(ℓ)	1116	1293	1911	e, g	g
Fe	1808, 1812					1550(s)	1680	1837(ℓ)	2033	2277	3008	e, g	g
Ag	1234					1200(s)	1305(ℓ)	1442	1607	1816	2485	e	
Au	1336					1570(ℓ)	1720	1896	2112	2388	3239	e	
Pt	2043, 2047					2160(ℓ)	2340	2550	2820	3140	4100	e, g	
K <sub>2</sub> O	(980)								1150±50†		1750±100†	e, g	c
Rb <sub>2</sub> O	(910)								1100±70†		1600±100†	e, g	c
Rb <sub>2</sub> O								(1086)§	(1183)§	(1300)§		e, g	c
Ca <sub>2</sub> O	763								1000±70†		1500±100†	e, g	c
CaO	2860±25								2650±50		3800±200	c, e	c
CaO	2570	(1100)	(1251)	(1450)	1725	(2124)	(2303)	(2515)	(2768)	(3080)††	(3975)††	a	d
SrO	2730±20								2400±100		3500±200	c	c
SrO	2703	(1087)	(1216)	(1380)	1595	(1890)	(2012)	(2154)	(2318)	(2505)	(2996)††	e	d
SrO		1030	1163	1337	1570	(1895)	(2035)	(2195)	(2380)	(2600)	(3200)††	-	f
BaO	2196±10								2120±100		3000±200	c, e	c
BaO		(821)	(939)	1095	1313	(1643)	(1793)	(1972)	(2190)	(2463)††	(3285)††	-	d
BaO		(816)	(935)	(1093)	1313	1650	1803	(1990)	(2220)	(2500)††	(3370)††	-	b
BaO		(911)	(1017)	1152	1330	1571	1672	(1786)	(1919)	(2070)	(2462)††	-	h
FeO	1641						(2060)°	(2240)°	(2480)°	(2760)°		e	a
FeO§	1644±1								2300±50†		3400±100†	c	c
FeO				(1730)§	(1890)§	(2060)§	(2210)§	(2380)§	(2580)§	(2810)§			c
Fe <sub>3</sub> O <sub>4</sub>	1870±2								1840±10†		2060±30†	c	c
Fe <sub>3</sub> O <sub>4</sub>						(1802)§	(1840)§	(1884)§	(1924)§	(1970)§			c
RbF	1048							(1075)	1185	1225	1681	e, g	g
RbCl	990							965	1050	1190	1654	e, g	g
RbBr	950							(935)	1039	1176	1625	g	g
RbI	911							900	1007	1140	1577	g	g
CaF	955						(880)	970	1099	1524		e, g	g
CaCl	918, 915						915	1003	1137	1573		e, g	g
CaBr	905						900	1007	1139	1573		g	g
CaI	894						(895)	997	1128	1553		g	g
SrF <sub>2</sub>	1673						(1680)	1850	2060	2750		e, g	g
SrCl <sub>2</sub>	1145						(1350)±100			(2300)±100		e, g	g
SrBr <sub>2</sub>	926						1300±100			(2150)±100		g	g
SrI <sub>2</sub>	788						(1100)±100			(1850)±100		g	g
AgF	708									1420		e, g	g
AgCl	728						1054	1168	1324	1837		e, g	g
AgBr	703						(995)	1120	1270	(1810)		g	g
AgI	830						958	1076	1233	(1779)		g	g

\* Values in parentheses ( ) are estimated or extrapolated except otherwise noted; (s) = solid phase; (ℓ) = liquid phase

† Total dissociation pressure:  $2M_{n/2}O(ℓ) \rightleftharpoons nM(g) + O_2(g)$

‡ Fe<sub>0.95</sub>O

° Vapor pressure of iron over iron oxide with O<sub>2</sub> pressure of 0.21 atm.

§ Vapor pressure of the metal over the oxide in air at 1 atmosphere; calc. from data for total dissociation pressure assuming equilibrium constant dependent on temperature only

†† Extrapolation not valid since melting point is exceeded

a. Adams, C. E., Farlow, N. H., Schell, W. R. "The Compositions, Structures, and Origins of Radioactive Fallout Particles," Naval Radiological Defense Laboratory Report NRDL-TR-209, Feb. 3, 1958

b. Blewett, J. P., Liebhafsky, H. A., Hennelly, E. F. "The Vapor Pressure and Rate of Evaporation of Barium Oxide," J. Chem. Physics, 7, 478-84 (1939); calc. from Equation:

For BaO:  $\log_{10} p, \text{ atm.} = 5.75 - (19,400/T)$   
where T = °K, valid over range 1200-1800°K

c. Brewer, L. "The Thermodynamic Properties of the Oxides and Their Vaporization Processes," Chem. Rev. 52, 1-76 (1953)

d. Claassen, A., Veenemans, C. F. "Vapor Pressure of BaO, SrO, CaO, and Their Mixtures from Rate of Evaporation Measurements," Z. Physik 80, 342-351 (1933)

For CaO:  $\log_{10} p, \text{ atm.} = 6.89 - (27,400/T)$   
where T = °K, valid over range 1600-1750°K

For BaO:  $\log_{10} p, \text{ atm.} = 5.99 - (19,700/T)$   
where T = °K, valid over range 1200-1500°K

For SrO:  $\log_{10} p, \text{ atm.} = 10.24 - (30,700/T)$   
where T = °K, valid over range 1500-1650°K

e. Glasner, A. "The Thermochemical Properties of the Oxides, Fluorides, and Chlorides to 2500°K," Argonne National Laboratory Report ANL-5750, 1957

f. Moore, G. E., Allison, H. W., Struthers, J. D. "The Vaporization of Strontium Oxide," J. Chem. Physics 18, 1572-1579 (1950); calc. from Equation:

For SrO:  $\log_{10} p, \text{ atm.} = 1.44 + 1.908 \log_{10} T - (25,950/T)$   
where T = °K, valid over range 700-1600°K

g. Quill, L. L. "The Chemistry and Metallurgy of Miscellaneous Materials: Thermodynamics," McGraw-Hill Book Co., New York, 1950

h. Herrmann, G. "On the Vapor Pressure of BaO," Z. Physikische Chemie, (B), 35, 298-308 (1937)

For BaO:  $\log_{10} p, \text{ atm.} = 10.56 - (26,000/T)$   
where T = °K, valid over range 1200 to 1600°K





*APPENDIX C*

**FISSION PRODUCT DECAY RELATIONSHIP**

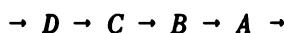


## APPENDIX C

### FISSION PRODUCT DECAY RELATIONSHIP

#### I. GENERAL DECAY EQUATIONS

For a chain reaction:



the general decay equations may be written

$$\frac{dm_A}{dt} = -\frac{m_A}{t_A} + \frac{m_B}{t_B} ; \quad (C-1)$$

$$\frac{dm_B}{dt} = -\frac{m_B}{t_B} + \frac{m_C}{t_C} ; \text{ etc.} \quad (C-2)$$

where  $m_A$ ,  $m_B$ , etc. are the net total yields of each radioactive component at time  $t$ ; and  $t_A$ ,  $t_B$ , etc. are the respective mean-lives of each component. The general integration of these equations leads to the result given in Table C-I.

While the over-all equation of Table C-I is given in terms of the yield for component  $A$ , it may be used to calculate the yield for any precursor by treating that precursor as the  $A$  component and dropping off any terms which would represent a nonexistent precursor.

The time at which the net yield of any component is a maximum can be computed by differentiating the general equation shown in Table C-I.. The general solution is too complex to solve explicitly for time. For a two component chain, however, an explicit solution can be given:

Table C-1

## GENERAL RELATIONSHIP FOR NET YIELD OF ANY COMPONENT IN CHAIN REACTION

For chain reaction:	$\rightarrow D \rightarrow C \rightarrow B \rightarrow A$
Mean life:	$t_D \quad t_C \quad t_B \quad t_A$
Independent yield:	$m_{oD} \quad m_{oC} \quad m_{oB} \quad m_{oA}$
Fraction continuing in chain:	$\eta_D \quad \eta_C \quad \eta_B \quad \eta_A$

$$m_A = +m_{oA} \left[ e^{-(t/t_A)} \right]$$

$$+ \eta_B m_{oB} \left[ \left( \frac{t_A}{t_A - t_B} \right) e^{-(t/t_A)} + \left( \frac{t_A}{t_B - t_A} \right) e^{-(t/t_B)} \right]$$

$$+ \eta_C \eta_B m_{oC} \left[ \left( \frac{t_A}{t_A - t_C} \right) \left( \frac{t_B}{t_A - t_B} \right) e^{-(t/t_A)} + \left( \frac{t_B}{t_B - t_C} \right) \left( \frac{t_A}{t_B - t_A} \right) e^{-(t/t_B)} + \left( \frac{t_C}{t_C - t_B} \right) \left( \frac{t_A}{t_C - t_A} \right) e^{-(t/t_C)} \right]$$

$$+ \eta_D \eta_C \eta_B m_{oD} \left[ \left( \frac{t_A}{t_A - t_D} \right) \left( \frac{t_A}{t_A - t_C} \right) \left( \frac{t_B}{t_A - t_B} \right) e^{-(t/t_A)} + \left( \frac{t_B}{t_B - t_D} \right) \left( \frac{t_B}{t_B - t_C} \right) \left( \frac{t_A}{t_B - t_A} \right) e^{-(t/t_B)} + \left( \frac{t_C}{t_C - t_D} \right) \left( \frac{t_C}{t_C - t_B} \right) \left( \frac{t_A}{t_C - t_A} \right) e^{-(t/t_C)} + \left( \frac{t_D}{t_D - t_C} \right) \left( \frac{t_D}{t_D - t_B} \right) \left( \frac{t_A}{t_D - t_A} \right) e^{-(t/t_D)} \right]$$

etc.

where  $m_A$  = total net yield of A at time t after fission.

NOTE: The above gives total net yield for components originating in the same chain. Any additions from another chain are not allowed for; depletions from the chain, however, are allowed for.

$$\frac{t_{\max, A}}{t_A} = \left[ \frac{1}{\left(\frac{t_A}{t_B}\right) - 1} \right] \ln \left\{ \frac{\left(\frac{t_A}{t_B}\right)}{1 + \left(\frac{m_{oA}}{m_{oB}}\right) \left[ \frac{\left(\frac{t_A}{t_B}\right) - 1}{\left(\frac{t_A}{t_B}\right)} \right]} \right\} \quad (\text{C-3})$$

## II. RELATIONSHIP BETWEEN HALF-LIFE AND MEAN-LIFE

Mean-life is defined by the equation

$$\frac{dm}{dt} = -\frac{m}{t_o} \quad (\text{C-4})$$

where  $m$  is the quantity of a given radioactive element at time  $t$ , when there is no replenishment by decay of a precursor, and  $t_o$  is the mean life, a constant for the component. Half-life,  $t_{1/2}$ , is related to mean-life by

$$t_o = \frac{t_{1/2}}{\ln 2} = (1.44) t_{1/2} \quad (\text{C-5})$$

## III. DECAY CURVES FOR THE MASS NUMBER 89, 90, and 137 CHAINS

Figures C-1, C-2, C-3, present decay curves for the 89, 90, and 137 chains formed in the fission of  $U^{235}$ . In general, three curves are shown for each component. One represents calculations based on the summary of fission product decay chains and yields presented by Blomeke and Todd.<sup>1033</sup> The other two are taken directly from decay values presented by Bolles and Ballou.<sup>1034</sup> One of the series of values by Bolles and Ballou is based on the fission yield theory of Glendinin, Coryell, and Edwards; the other is based on the theory of Present.

The curves of Figures C-1, C-2, C-3, give the quantity of a specific component present at a given time, expressed as a percentage of the maximum amount of that component present at any time. The legend gives the corresponding yield values (should absolute quantities be desired for any component) as well as the respective half-lives assumed for each series

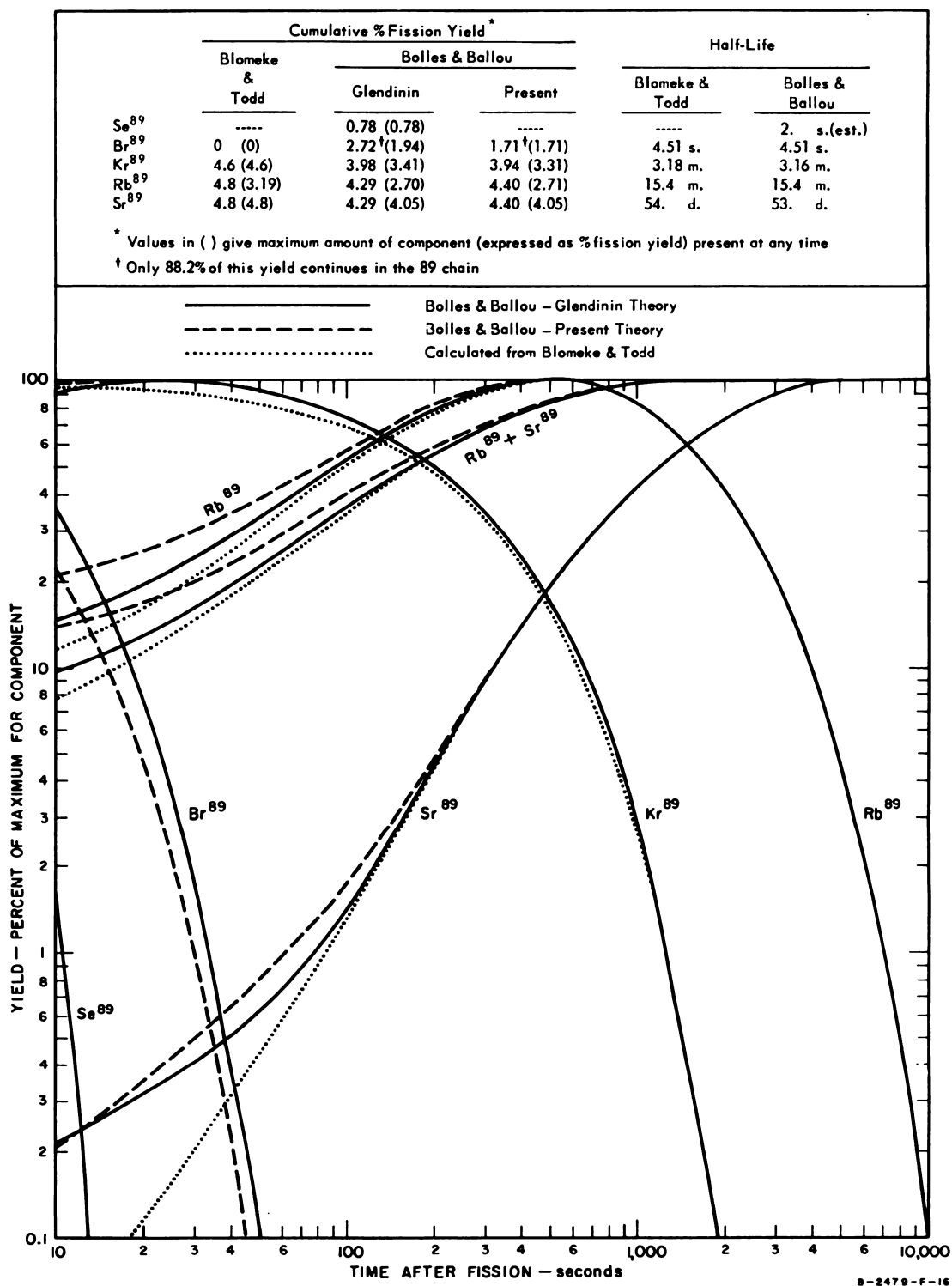


FIG. C-1  
FISSION OF U<sup>235</sup>, MASS-89-CHAIN DECAY

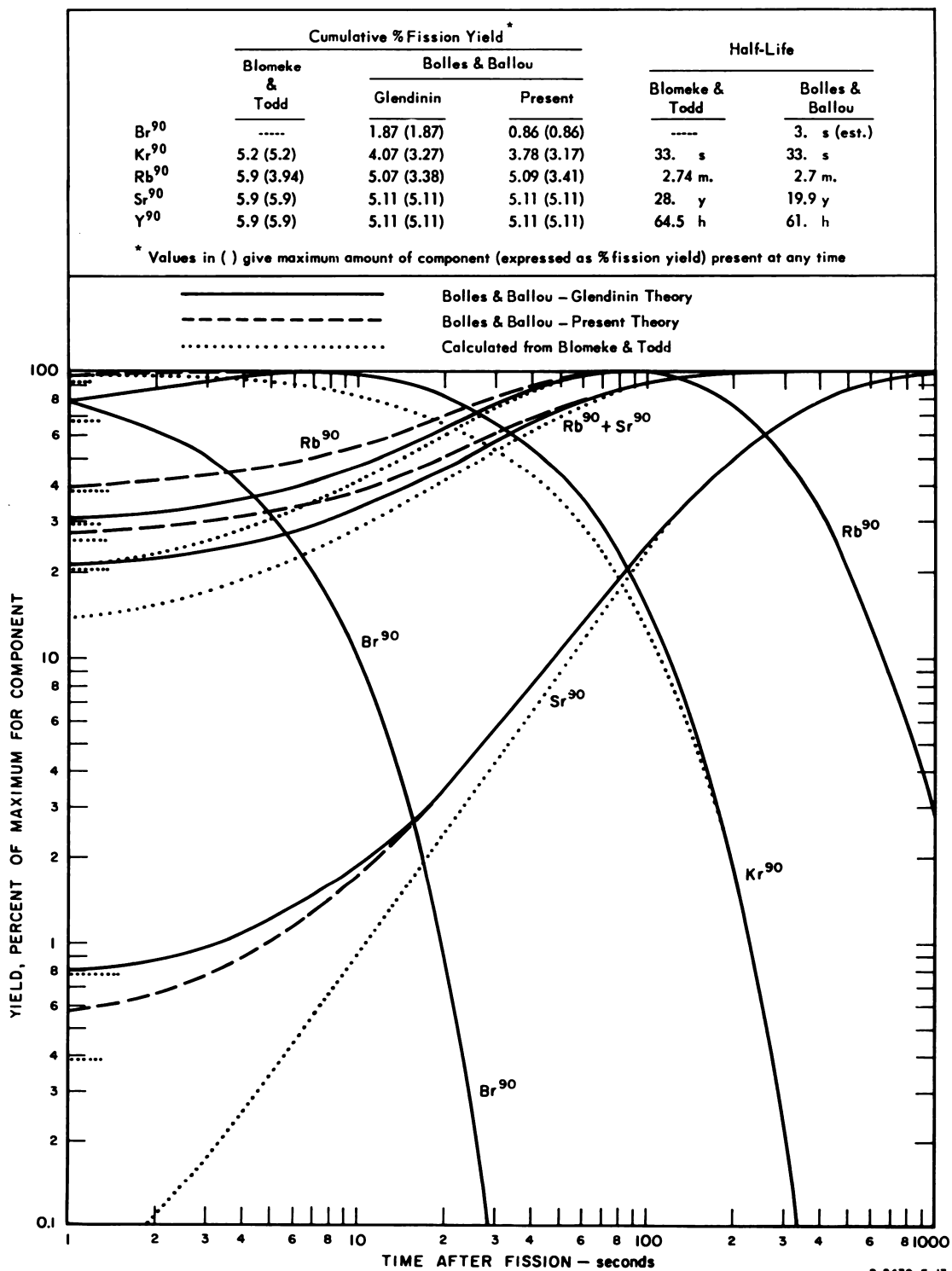
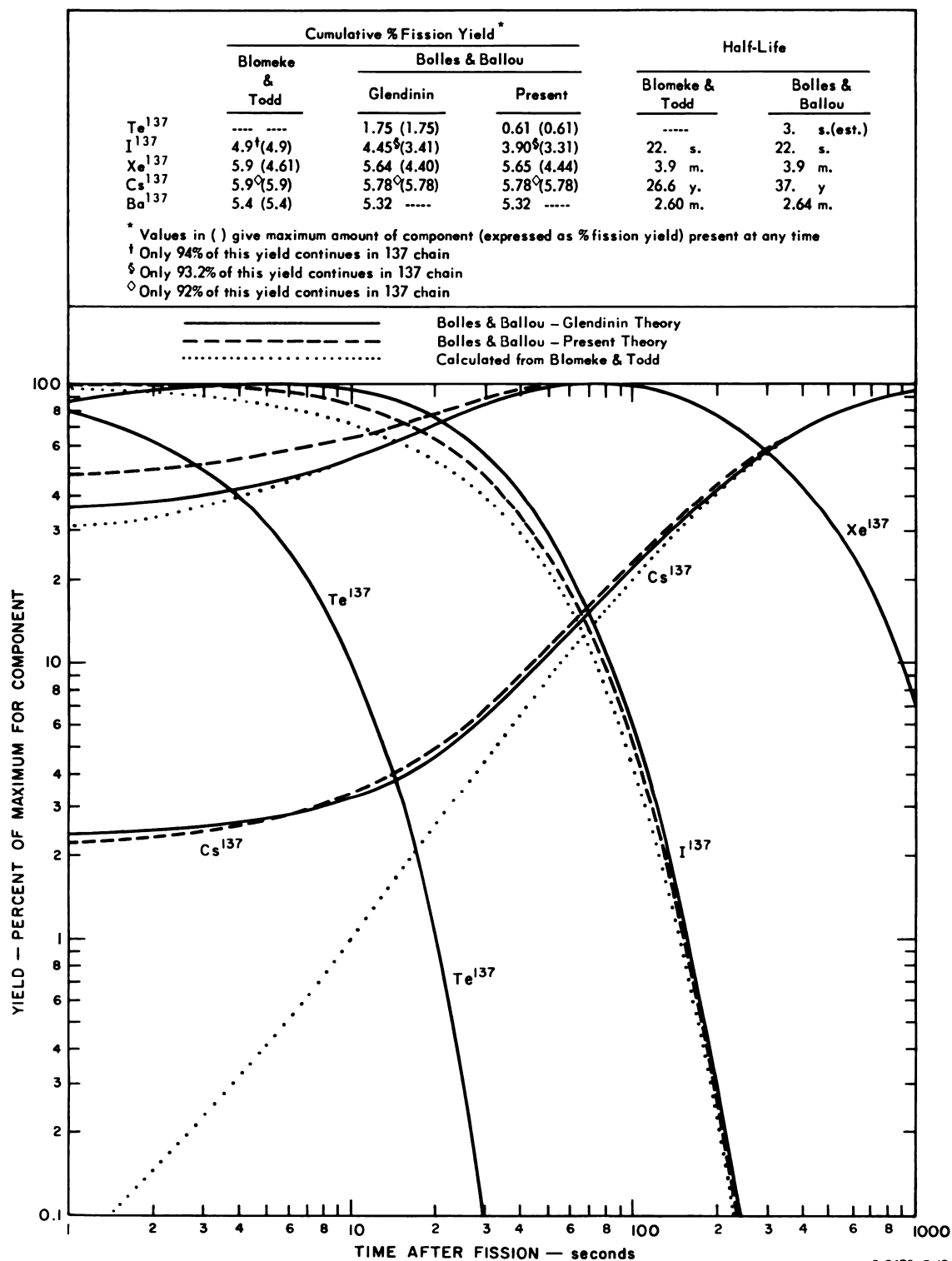


FIG. C-2  
FISSION OF U<sup>235</sup>, MASS-90-CHAIN DECAY





D-2479-F-18

of decay curve. It should be noted that Bolles and Ballou assumed the older values for the half-life of  $\text{Sr}^{90}$  and  $\text{Cs}^{137}$ . This, however, will not influence the values shown in Figures C-2 and C-3, since these half-life values do not enter into the computation for the time interval here considered. In the case of  $\text{Sr}^{89}$  there is also an inconsistency in the independent yield values reported by Bolles and Ballou and the maximum yield of  $\text{Sr}^{89}$  given in their summary of decay rates. The maximum yield of  $\text{Sr}^{89}$  is given as 4.05%, whereas it should be very close to 4.29%, based on the independent yield values given. This discrepancy has not been resolved. The curves in Figure C-1 have been based on the 4.05% value.

Baerg and Bartholomew<sup>1027</sup> give recent (1957) data on  $\text{Sr}^{90}$ , reporting a 4.74% yield and a half-life of 50.4 days. This may be compared with the corresponding values shown in the legend of Figure C-2.

In comparing the various sets of values in Figures C-1, C-2, C-3, it is apparent that the primary difference in the three values for each component occurs in the early history. Bolles and Ballou have included estimates for early short-lived precursors which are neglected by Blomeke and Todd. In the later history, however, there is essentially no difference in the three values when presented on a relative basis as is done in Figure C-1, C-2, C-3. There is, of course, the absolute difference inherent in the different absolute yields given in the legend.

#### IV. DISCUSSION OF DECAY HISTORY

In the case of the Mass-90 chain, the precursor of  $\text{Rb}^{90}$  and  $\text{Sr}^{90}$  is an inert gas  $\text{Kr}^{90}$ , except for a small amount of short-lived  $\text{Br}^{90}$ . Thus, unless means can be devised for controlling an inert gas, any control measures must be concerned with times after fission at which the  $\text{Kr}^{90}$  has decayed into  $\text{Rb}^{90}$  or  $\text{Sr}^{90}$ . From Figure C-2 it is apparent that it requires 200 seconds after fission before 50% of the Mass-90 chain material is in the form of  $\text{Sr}^{90}$  and 600 seconds before 90% is in the  $\text{Sr}^{90}$  form. Rubidium<sup>90</sup> hits a maximum concentration at 90 seconds, because of its subsequent decay to  $\text{Sr}^{90}$ .

Since either  $\text{Rb}^{90}$  or  $\text{Sr}^{90}$  are potentially subject to control, a better assessment of the control problem is found by considering the time history of the  $\text{Rb}^{90}$ ,  $\text{Sr}^{90}$  sum or the residual  $\text{Kr}^{90}$ . Thus it requires approximately 30 seconds before 50% of the Mass-90 chain is in the form of either  $\text{Rb}^{90}$  or  $\text{Sr}^{90}$  (50% still in form of  $\text{Kr}^{90}$ ) and 100 seconds before 90% is in the

form of either  $\text{Rb}^{90}$  or  $\text{Sr}^{90}$  (10% still in the form of  $\text{Kr}^{90}$ ). It may be concluded, therefore, that in order to achieve a reasonably complete ultimate control of  $\text{Sr}^{90}$ , any control measures can be effective only if applied 100 or more seconds after fission. Earlier application of control measures can achieve no better than partial control (<90%).

Similarly, for the control of  $\text{Cs}^{137}$ , the best assessment of the control problem is found by considering either the history of  $\text{Cs}^{137}$  or the residual  $\text{Xe}^{137}$ . Thus from Figure C-3 it is apparent that control measures for  $\text{Cs}^{137}$  must be applied at times later than 800 seconds after fission in order to be effective. If applied as early as 250 seconds after fission, they could be only some 50% effective at best.

Although the Mass-89 chain is not a long-range hazard, it is interesting to note that any control measures would have to be applied later than 600 seconds after fission or very nearly the same as for the Mass-137 chain.

*APPENDIX D*

**DIFFUSIONAL GROWTH AND DEPOSITION OF PARTICLES**



## APPENDIX D

### DIFFUSIONAL GROWTH AND DEPOSITION OF PARTICLES

#### I DIFFUSION TO PARTICLES

The rate of deposition or condensation on a sphere in infinite space by diffusion from a quiescent atmosphere is given by

$$w = 2\pi D_b D_v (c_o - c_s), \quad (D-1)$$

where  $D_v$  is the diffusion coefficient of the diffusing material, the latter being present at a concentration of  $c_o$  in the ambient atmosphere.

#### II DIFFUSIONAL DEPOSITION OF AEROSOLS ON LARGER PARTICLES

If the diffusing material is an aerosol,  $D_v$  is actually  $D_{vp}$ ,  $c_o$  is  $c_p$ , and  $w$  is  $w_p$ . If it is assumed that all particles adhere upon touching the collecting sphere,  $c_s$  may be taken as 0. Equation (D-1) then becomes

$$w_p = 2\pi D_b D_{vp} c_p. \quad (D-2)$$

This gives the deposition rate on a *single* collecting sphere. For a gas volume  $V$ , containing  $n_b$  collecting spheres per unit volume, the total particle deposition rate is

$$w_p = 2\pi D_b n_b V D_{vp} c_p. \quad (D-3)$$

But, since deposition on the collector sphere represents a depletion of particles in the gas volume,

$$w_p = - \left( \frac{dc_p}{dt} \right) V. \quad (D-4)$$

Hence, Equation (D-3) becomes

$$\frac{dc_p}{c_p} = -2\pi n_b D_b D_{vp} dt \quad . \quad (D-5)$$

Integrating between the limits  $c_p = c_{p0}$  at  $t = 0$  and  $c_p = c_p$  at  $t = t$ ,

$$\ln\left(\frac{c_p}{c_{p0}}\right) = -2\pi n_b D_b D_{vp} t \quad (D-6)$$

or

$$\frac{c_p}{c_{p0}} = e^{-2\pi n_b D_b D_{vp} t} \quad . \quad (D-7)$$

But the efficiency or completeness of deposition,  $\eta$ , may be expressed as

$$\eta = \frac{c_{p0} - c_p}{c_{p0}} = 1 - \frac{c_p}{c_{p0}} \quad (D-8)$$

or

$$\ln\left(\frac{1}{1 - \eta}\right) = N_t = 2\pi n_b D_b D_{vp} t \quad . \quad (D-9)$$

This gives the basic relationship for the effectiveness of deposition of small particles on large ones by diffusion from a quiescent fluid.

Equation (D-9) may also be written

$$\frac{t}{N_t} = \frac{1}{2\pi(n_b D_b) D_{vp}} = \frac{\rho_b D_b^2}{12 c_b D_{vp}} \quad . \quad (D-10)$$

Figure 8 presents a plot of this equation. In the usual case where the collecting bodies involve a size distribution rather than uniform collector particles, the term  $n_b D_b$  should be replaced by

$$\sum_{n_b=0}^{n=n_b} D_b dn_b$$

in order to make an appropriate allowance. In terms of concentration, the correct average particle diameter for use in Equation (D-10) is given by

$$D_{b,av} = \sqrt{\frac{\sum_{n_b=0}^{n_b=n_b} D_b^3 dn_b}{\sum_{n_b=0}^{n_b=n_b} D_b dn_b}} \quad (D-11)$$

Where particulates involve a size distribution, it is often customary to express average size in such terms as mass median diameter (meaning that 50% of the mass resides in particles smaller or larger than the mass median size). If the distribution function is known, the effective average size,  $D_{b,av}$ , can be calculated directly from the mass median diameter,  $D_{bmw}$ . If, for example, the size distribution follows a log-probability function, it is readily shown that

$$D_{b,av} = D_{bmw} e^{(1/2) \ln^2 \sigma} \quad (D-12)$$

The following table gives values of the ratio ( $D_{b,av}/D_{bmw}$ ) for various values of  $\sigma$ :

STANDARD GEOMETRIC DEVIATION, $\sigma$	$\left(\frac{D_{b,av}}{D_{bmw}}\right)$
1*	1.000
2	1.272
3	1.828
4	2.62
6	4.98

\* this is the case for particles of uniform size

It is apparent from these values that for a standard geometric deviation of 3, the effective average particle size for purposes of simple diffusional scavenging is twice the mass median diameter. Thus, such a material would not be as effective a scavenging agent as a uniform material of the same mass median diameter.



### III DIFFUSIONAL GROWTH OF CONDENSATION AEROSOLS

Once a nucleus has formed, the rate of particle growth, as limited by diffusional considerations, is given by Equation (D-1). Since we are considering an aerosol particle,  $D_b$  is actually  $D_p$ . Also, since the deposition on the particle determines the growth of the particle

$$\begin{aligned} w &= \frac{d\left(\frac{\pi\rho_p D_p^3}{6}\right)}{dt} \\ &= \left(\frac{\pi\rho_p D_p^2}{2}\right) \left(\frac{dD_p}{dt}\right) \end{aligned} \quad (D-13)$$

Therefore, Equation (D-1) becomes

$$\rho_p D_p dD_p = 4D_v (c_o - c_s) dt. \quad (D-14)$$

Assuming a constant value of  $(c_o - c_s)$  (i.e., neglecting depletion of the vapor phase), Equation (D-14) may be integrated over the range  $D_p = 0$  at  $t = 0$  to  $D_p = D_p$  at  $t = t$  to give

$$t = \frac{\rho_p D_p^2}{8D_v (c_o - c_s)} \quad (D-15)$$

The derivation of this equation has neglected: (1) time of nucleation; (2) the effect of depletion of the vapor phase; and (3) the effect of flow patterns on mass transfer.

Allowance for flow patterns would increase mass transfer rates and hence rate of growth. However, for the range of sizes and velocities normally involved, the increase in mass transfer rate over that in a quiescent fluid is negligible. Allowances for nucleation and vapor phase depletion will result in lower rates of growth than given by Equation (D-15). Consequently Equation (D-15) may be regarded as giving the minimum time that it takes to grow a particle of size  $D_p$ ; or, conversely, the maximum size particle that can be grown in time  $t$  by vapor phase condensation. A plot of Equation (D-15) is given in Figure 6.

*APPENDIX E*

**PARTICLE SCAVENGING**



## APPENDIX E

### PARTICLE SCAVENGING

#### I GENERAL RELATIONSHIP

As a mass of scavenging particles falls through a cloud, each such particle will scavenge those particles which are suspended in the path of the gas swept out. As each scavenging particle traverses the cloud it will traverse a gas volume equal to the horizontal projected area of the particle normal to the direction of relative motion times the cloud height. The total cloud area is  $A_c dH$ . Therefore, from the definition of target efficiency,

$$\frac{-dc_p}{c_p} = \eta_t \left( \frac{A_b dH}{A_c dH} \right) \left( \frac{dM_b}{M_b} \right) = \eta_t \left( \frac{A_b}{M_b} \right) \left( \frac{dM_b}{A_c} \right), \quad (\text{E-1})$$

where  $dc_p$  is the change in concentration due to the passage of a small mass of scavenging particles  $dM_b$ .

Now, integrating between the limits  $c_p = c_{p0}$  at  $M_b = 0$  to  $c_p = c_p$  at  $M_b = M_b$ ,

$$\ln \left( \frac{c_{p0}}{c_p} \right) = \eta_t \left( \frac{A_b}{M_b} \right) \left( \frac{M_b}{A_c} \right). \quad (\text{E-2})$$

But, since

$$\ln \left( \frac{c_{p0}}{c_p} \right) = \ln \left( \frac{1}{1 - \eta} \right) = N_t, \quad (\text{E-3})$$

then

$$N_t = \eta_t \left( \frac{M_b}{A_c} \right) \left( \frac{A_b}{M_b} \right). \quad (\text{E-4})$$

If the collector particles are spherical,

$$\frac{A_b}{m_b} = \frac{\left(\frac{\pi D_b^2}{4}\right)}{\left(\frac{\pi \rho_b D_b^3}{6}\right)} = \frac{3}{2 \rho_b D_b} \quad , \quad (\text{E-5})$$

and Equation (E-4) becomes

$$N_t = \frac{3 \eta_t (M_b / A_c)}{2 \rho_b D_b} \quad , \quad (\text{E-6})$$

or

$$\frac{M_b}{A_c} = \frac{2 \rho_b D_b N_t}{3 \eta_t} \quad . \quad (\text{E-7})$$

The term  $A_c$  as used here applies to the area of cloud in a plane normal to the direction of relative motion between the scavenging particles and cloud. The derivation also assumes that all the scavenging particles sweep through the entire cloud.

This same result could be obtained by recognizing that this scavenging system is the mathematical equivalent of an air filter system in which the cloud is passed through a stationary filter composed of the scavenging particles. Wright,<sup>32\*</sup> gives a relationship for the transfer units for flow through such a fibrous filter. His relationship may be generalized for any shape of collecting body as

$$N_t = \eta_t \left( \frac{M_b}{A_c} \right) \left( \frac{s_{vb}}{\rho_b} \right) \quad . \quad (\text{E-8})$$

For spherical particles

$$s_{vb} = \frac{\left(\frac{\pi D_p^2}{4}\right)}{\left(\frac{\pi D_b^3}{6}\right)} = \frac{3}{2 D_b} \quad (\text{E-9})$$

---

\* See Eq. (2) in this reference.

Hence

$$N_t = \frac{3\eta_t (M_b/A_c)}{2\rho_b D_b} \quad (\text{E-10})$$

which is identical with Equation (E-6) above.

Equation (E-6) may be written in working units as

$$\frac{M_b}{A_c} = 1.90 \left( \frac{\rho_b D_b N_t}{\eta_t} \right), \quad (\text{E-11})$$

where  $(M_b/A_c)$  is in tons/sq mi,  $\rho_b$  is specific gravity,  $D_b$  is in microns, and  $N_t$  and  $\eta_t$  are dimensionless. A plot of Equation (E-11) is given in Figure 10.

## II APPLICATION

The use of Equation (E-11) depends upon being able to assign a value to  $\eta_t$ . The value of  $\eta_t$  depends on the particle size and density of the scavenging material as well as upon the size and density of scavenged material.

To ascertain a minimum value of required scavenging material, assume the following values:

- $D_b = 100$  microns: this is about the minimum size that could be used and still achieve local fallout of the scavenging particles
- $\rho_b = 2.6$  g/cu cm (for sand)
- $N_t = 3$  (corresponding to 95% scavenging efficiency)
- $\eta_t = 1$  (essentially maximum possible value)

For these conditions,  $M_b/A_c$  is 1480 tons/sq mi. Thus, it may be concluded that to attain reasonably effective scavenging, the quantity of scavenging agent must exceed 1000 tons/sq mi. Actually it may have to be greatly in excess of this, since  $\eta_t$  may be radically smaller than 1.

Wright<sup>328</sup> gives bases for estimating  $\eta_t$  for the case of cylindrical scavenging bodies such as are used in filters. Nevertheless these can be used to assess the order of magnitude of  $\eta_t$  when dealing with nominally

spherical scavenging particles. Assuming that the scavenged particles are primarily in the range of 0.1 to 1 micron diameter, one might expect  $\eta_t$  to be on the order of 0.01 on the basis of data given by Wright. Thus, referring to the above example, on the order of 150,000 tons of scavenging particles/sq mile of cloud would be required to achieve a 95% scavenging efficiency.

### III BASES FOR ASSESSING $\eta_t$ :

A minimum value of  $\eta_t$  can be calculated by assuming that collection proceeds by diffusion of the scavenged particle to the scavenging particle in essentially quiescent air. For this purpose, Equation (D-10) of Appendix D may be applied:

$$N_t = 12 \frac{c_b D_{vp} t}{\rho_b D_b^2} . \quad (E-12)$$

In this case, since  $t = H/u_b$  and  $M_b = c_b H A_c$ ,

$$N_t = 12 \left( \frac{M_b}{A_c} \right) \left( \frac{D_{vp}}{\rho_b u_b D_b^2} \right) . \quad (E-13)$$

By combining Equations (E-10) and (E-13),

$$\eta_t = 8 \left( \frac{D_{vp}}{u_b D_b} \right) = 8 N_{sd} . \quad (E-14)$$

Values of  $\eta_t$  calculated from Equation (E-14) would be minimum values (hence maximum for  $M_b/A_c$ ), since the actual flow past the scavenging particle will increase diffusional deposition over that given by Equation (E-14).

The general relations for diffusional deposition of aerosols on spheres, allowing for hydrodynamics, have not yet been worked out. Experimental data as well as simplified theoretical approaches are available for diffusional deposition of aerosols on cylindrical bodies. For spheres, Greenfield<sup>238</sup> has applied the Smoluchowski equations, which are basically similar to Equation (E-14) above.

Experimental data on mass transfer to spheres and cylinders have been correlated by Froessling as reported by Ranz.<sup>296</sup> For spheres, he obtained a relationship which, for application to diffusional aerosol deposition, may be written in the forms:

$$\begin{aligned}\eta_t &= 8N_{sd} \left[ 1 + (0.30) N_{Re}^{1/6} N_{sd}^{-1/3} \right] \\ &= 2.40 N_{sd}^{2/3} N_{Re}^{1/6} \left[ 1 + 3.33 N_{sd}^{1/3} N_{Re}^{-1/6} \right] .\end{aligned}\quad (E-15)$$

As written in the first form, it should be noted that the equation is identical to Equation (E-14), except for the term in brackets. The term in brackets allows for the additional hydrodynamic effect. The chief drawback to this equation is that it was developed for the diffusion of liquids and vapors\* and involved conditions many orders of magnitude removed from those encountered with aerosols. Consequently the extrapolation to aerosols becomes questionable. It should be noted that the corresponding equation for cylinders, subject to the same objection, has yielded results which are of the proper order of magnitude when compared with actual aerosol filtration data. In that case, the equation gave values of  $\eta_t$  which were generally low by a factor of 2 to 3. On this basis we may justify use of this relationship as a first approximation.

Table E-I gives values calculated for specific conditions on the basis of both Equations (E-14) and (E-15). It will be noted from these values that the hydrodynamic effects on diffusion can become very pronounced. It is interesting to compare the required values of  $M_b/A_c$  given in Table E-I with values of  $M_b/A_c$  corresponding to various quantities of rainfall:

RAINFALL, in.	CORRESPONDING VALUE OF $M_b/A_c$ , tons/sq mi
10	724,000
1	72,400
0.1	7,240

The above equations do not consider the interactive effects of other deposition mechanisms. These mechanisms will result in a further increase in the value of  $\eta_t$ . These added effects will be most pronounced the larger

\* Data based on a range in value of the Schmidt number,  $\mu/\rho D_v$ , of 0.5 to 1000



the scavenged particle. Quantitative means are available for predicting  $\eta_c$  for deposition on cylindrical bodies, allowing for the combined effects of diffusion, inertia, and interception.<sup>328</sup> Such generalized data have not been developed for spherical collecting bodies.

Table E-I  
CALCULATED VALUES OF TARGET EFFICIENCY AND  
SCAVENGING REQUIREMENTS FOR DIFFUSIONAL DEPOSITION

ALTITUDE ABOVE SEA LEVEL, * ft.	$D_b'$ microns	$u_b'$ ft./sec	$D_p'$ microns	$D_{vp}'$ cm <sup>2</sup> /sec	$N_{Re}'$ dimensionless	$N_{sd}'$ dimensionless	$\eta_t$		$M_b A \$$ tons/sq mi
							From Eq. (E-14)	From Eq. (E-15)	
0	100	0.83	0.01	$5.05 \times 10^{-4}$	1.75	$1.985 \times 10^{-3}$	$1.59 \times 10^{-2}$	$5.75 \times 10^{-2}$	9,900
			0.1	$6.57 \times 10^{-6}$		$2.58 \times 10^{-5}$	$2.06 \times 10^{-4}$	$25.0 \times 10^{-4}$	228,000
			1.0	$2.72 \times 10^{-7}$		$1.07 \times 10^{-6}$	$8.55 \times 10^{-6}$	$284. \times 10^{-6}$	2,010,000
10,000	100	0.91	0.01	$6.55 \times 10^{-4}$	1.48	$2.37 \times 10^{-3}$	$1.90 \times 10^{-2}$	$6.45 \times 10^{-2}$	8,800
			0.1	$8.06 \times 10^{-6}$		$2.92 \times 10^{-5}$	$2.34 \times 10^{-4}$	$26.6 \times 10^{-4}$	214,000
			1.0	$2.81 \times 10^{-7}$		$1.02 \times 10^{-6}$	$8.14 \times 10^{-6}$	$267. \times 10^{-6}$	2,130,000
0	1000 (rain drops)	12.9	0.01	$5.05 \times 10^{-4}$	270	$1.28 \times 10^{-5}$	$1.03 \times 10^{-4}$	$34.5 \times 10^{-4}$	1,650,000
			0.1	$6.57 \times 10^{-6}$		$1.67 \times 10^{-7}$	$1.34 \times 10^{-6}$	$186. \times 10^{-6}$	30,600,000
			1.0	$2.72 \times 10^{-7}$		$6.91 \times 10^{-9}$	$5.52 \times 10^{-8}$	$2220. \times 10^{-8}$	257,000,000
10,000	1000 (rain drops)	14.8	0.01	$6.55 \times 10^{-4}$	240	$1.45 \times 10^{-5}$	$1.16 \times 10^{-4}$	$36.6 \times 10^{-4}$	1,560,000
			0.1	$8.06 \times 10^{-6}$		$1.79 \times 10^{-7}$	$1.43 \times 10^{-6}$	$191. \times 10^{-6}$	29,800,000
			1.0	$2.81 \times 10^{-7}$		$6.22 \times 10^{-9}$	$4.97 \times 10^{-8}$	$2020. \times 10^{-8}$	282,000,000

\* Atmospheric conditions based on corresponding ICAO Standard Atmosphere (Appendix A)

† Assuming  $\rho_b = 1$  g/cu cm and that  $u_b$  is terminal fall velocity of scavenging particle

§ Calc. from Equation (E-11), using  $\eta_t$  obtained from Equation (E-15), and for  $N_t = 3$  (corresponding to 95% scavenging efficiency)



## **APPENDIX F**

### **BIBLIOGRAPHY**

<b>I</b>	<b>INTRODUCTION . . . . .</b>	<b>F- 3</b>
<b>II</b>	<b>UNCLASSIFIED REFERENCES . . . . .</b>	<b>F- 5</b>
	<b>A. General . . . . .</b>	<b>F- 5</b>
	<b>B. Fireball and Cloud Conditions . . . . .</b>	<b>F-11</b>
	<b>C. Aerosol Formation . . . . .</b>	<b>F-13</b>
	<b>D. Deposition and Retention on Surfaces . . . . .</b>	<b>F-18</b>
	<b>E. Atmospheric Transport, Distribution, and Subsidence . . . . .</b>	<b>F-28</b>
	<b>F. Effects of Fallout . . . . .</b>	<b>F-50</b>
	<b>G. Properties (Physical, Chemical, Nuclear, Radiological) . . . . .</b>	<b>F-73</b>
<b>III</b>	<b>CLASSIFIED REFERENCES . . . . .</b>	<b>F-79</b>
<b>IV</b>	<b>CROSS-INDEX OF CLASSIFIED REFERENCES BY REPORT CODE NUMBER . . . . .</b>	<b>F-89</b>



## *APPENDIX F*

### **BIBLIOGRAPHY**

#### **I. INTRODUCTION**

In compiling the following unclassified bibliography, the following abstract sources were consulted:

- a.* Agricultural Index
- b.* APCA Abstracts (Air Pollution Control Association)
- c.* ASTIA Technical Abstract Bulletin
- d.* Atmospheric Pollution Bulletin (Great Britain, Department of Scientific and Industrial Research. Fuel Research Station)
- e.* Battelle Technical Review
- f.* Bibliography of Agriculture (U. S. Department of Agriculture Library)
- g.* Biological Abstracts
- h.* British Abstracts (now part of J. Appl. Chem. and British Abstracts of Medical Sciences)
- i.* Chemical Abstracts (American Chemical Society)
- j.* Chemisches Zentralblatt
- k.* Current Chemical Papers
- l.* Engineering Index
- m.* Meteorological Abstracts and Bibliography
- n.* National Advisory Committee for Aeronautics, Index of NACA technical publications
- o.* Nuclear Science Abstracts
- p.* Science Abstracts, Sect. A: Physics Abstracts
- q.* SIPRE (Snow, Ice, and Permafrost Research Establishment) Abstracts
- r.* Stanford Research Institute Air Pollution Bibliographic File

- s. United Nations. Proceedings of the International Conference on the Peaceful Uses of Atomic Energy, Geneva (August 8 to August 20, 1955)
- t. U.S. Atomic Energy Commission. Annotated Bibliography on Fall-out Resulting from Nuclear Explosions, by A. G. Hoard, M. Eisenbud and J. H. Harley. (NYO-4753 and Suppls. 1 and 2) (September 1956)
- u. U.S. Atomic Energy Commission. Annotated Bibliography on the Transport and Deposition of Atomic Debris, by Robert J. List. (TID-3061)(January 1956)
- v. U.S. Department of Health, Education and Welfare, Public Health Engineering Abstracts. Robert A. Taft Sanitary Engineering Center
- w. U.S. Library of Congress. Air Pollution Bibliography, Vol. 1. J. R. Gibson, W. E. Culver, and M. E. Kurz, Public Health Service, Health, Education and Welfare Department (1957)
- x. U.S. Mines Bureau. Air Pollution Bibliography, by S. J. Davenport and G. G. Morgis. Bulletin 537(1954)
- y. University of Cincinnati. Annotated Bibliography, The Effects of Atmospheric Pollution on the Health of Man (1957)

The classified references were obtained primarily from Nuclear Science Abstracts and from the files of the University of California, Radiation Laboratory, Livermore.

Bibliographic references marked with an asterisk (\*) were not consulted during this study because either (1) the reference was not obtainable in time, or (2) the reference was considered as of doubtful utility in achieving the objectives of the present study, or (3) the reference duplicated the material contained in another reference.

## II. UNCLASSIFIED REFERENCES

### A. GENERAL

- 1.\* Anonymous. Nuclear warfare. A bibliography. (Covering the period June 1955-June 1956. Congr. School Library, Fort Belvoir, Va. NP-6387, 99 p (November 1956)
- 2.\* Anderson, E. E. Manual on radiological protection for civilian defense. Oak Ridge National Laboratory, M-4514, 173 p (April 1950)
3. Andrews, H. L. Radioactive fallout from bomb clouds. *Science* **122**, 453-56 (September 9, 1955)
- 4.\* Anthony, L. J. Sources of information on atomic energy. AERE Lib/L-1 (2nd ed.). 25 p (July 31, 1957)
5. Anthony, S. A. and R. Crook. Technical photography, documentary. Operation Teapot (USAEC). WT-1169, 34 p (June 1956)
- 6.\* Argonne National Laboratory. Radiological Physics Division Semi-annual report for January-June 1957. ANL-5755 (July 1957)
- 7.\* Atomic Energy Research Establishment. Published information on the decay of fission products (a bibliography). AERE-Inf/Bib-63, 22 p (March 20, 1950)
8. Bishop, A. S. Controlled fusion. *Nucleonics* **15**, 128-30 (1957)
- 9.\* Bugher, J. C., J. Coursaget and J. F. Loutit (eds). Biological Sciences. Progress in Nuclear Science. McGraw-Hill Book Co., New York (1956)
10. Burke-Gaffney, T. N. and K. E. Bullen. Seismological and related aspects of the 1954 hydrogen bomb explosions. *Australian J. Phys.* **10**, 130-6 (1957)
- 11.\* Cockcroft, J. A general lecture on atomic energy covering the whole field. Assoc. Sci. Tech. Soc., S. Africa, Ann. Proc., 43-59 (1948-49)
12. Commoner, B. The fallout problem. *Science* **127**, 1023-26 (1958)
13. Dunning, Gordon M. Effects of nuclear weapons testing. *Scientific Monthly* **81**, 6, 265-70 (1955)
14. Dunning, Gordon M. Immediate radiations from nuclear detonations. *J. Wash. Acad. of Science.* **47**, 189-95 (1957)
15. Dunster, H. J. Contamination of surfaces by radioactive materials: the derivation of maximum permissible levels. *Atomics (Brit.)* **6**, 233-9 (1955)

---

\* References thus marked were not consulted either because they were not available in time or because the contents were judged to be of remote relevancy to the immediate objective.



- 16.\* Fuks, N. A. Mechanics of aerosols. Moskva, Akademia Nauk SSSR, 351 p (1955)
17. Glasstone, Samuel, ed. Effects of atomic weapons. U.S. Govt. Printing Office, Washington, D.C. NYO-4753 (Revised September 1950)
18. Glasstone, Samuel, ed. The effects of nuclear weapons. U.S. Govt. Printing Office, Washington, D.C. NYO-4753-S1, 587 p (1957)
19. Green, H. L. and W. R. Lane. Particulate Clouds: Dusts, Smokes and Mists. E. and F. N. Spon, London, 425 p (1957)
- 20.\* Herbst, W. Radioactive aerosols and the problem of protection in the operation of nuclear reactors. Z. Aerosol-Forsch u Therap. **4**, 473-505 (1955)
21. Hoard, A. G., M. Eisenbud and J. H. Harley. Annotated bibliography on fallout resulting from nuclear explosions. US A.E.C. Report NYO-4753 (September 1956); NYO-4753 (Suppl. 1) (November, 1956); NYO-4753 (Suppl. 2) (November, 1957)
- 22.\* Hutcheson, J. A. Engineering problems in atomic energy for industrial application. Mech. World **123**, 427-28 (1948)
- 23.\* Infeld, L. and A. Schild. On the motion of test particles in general relativity. Rev. Mod. Phys. **21**, 408-13 (1949)
- 24.\* Kane, E. P. and G. J. Maslach. Impact-pressure interpretation in a rarefied gas at supersonic speeds. Index of NACA Technical Publications. TN-2210 (1949-May 1951)
- 25.\* Khrgian, A. Kh. Large explosions and atmospheric phenomena. Priroda **46**, 3, 31-7 (1957)
- 26.\* Lacy, W. J. Decontamination of radioactively contaminated water by slurring with clay. Ind. Eng. Chem. **46**, 1061-65 (1954)
- 27.\* LaMer, V. K. The preparation, collection and measurement of aerosols. In Proceedings of First National Air Pollution Symposium. Stanford Research Institute, Menlo Park, California, p 5-13 (1949)
- 28.\* Langstroth, G. O., et al. Laboratory study of visibility through clouds. Canada Jour. Res. **25**, 49-57 (1947)
29. Lapp, Ralph. Strontium limits in peace and war. Bull. of Atomic Scientists **12**, 8, 287-9 and 320 (1956)
30. Libby, W. F. Radioactive fall-out. Bull. Atom. Scientists **11**, 256-60 (1955)
31. Libby, W. F. Radioactive fallout. Natl. Safety News, pp 60, 62, 98, and 99 (November 1955)
32. Libby, W. F. Radioactive strontium fallout. Proc. Natl. Acad. Sci. US **42**, 365-90 (1956)
33. Libby, W. F. Current research findings on radioactive fallout. Proc. Natl. Acad. Sci. US **42**, 945-62 (1956)

34. Libby, W. F. Radioactive fallout and radioactive strontium. *Science* **123**, 657-60 (1956)
35. Libby, W. F. Radioactive fallout. *Proc. Natl. Acad. Sci. US* **43**, 758-75 (1957)
36. Libby, W. F. Degree of hazard to humanity from radioactive fallout from nuclear weapons tests. *Bull. Atom. Scientists* **12**, 206-7 (1957)
37. Libby, W. F. Radioactive Fallout. Remarks before Swiss Academy of Medical Sciences, Lausanne, Switzerland, March 27, 1958
- 38.\* Lauderdale, R. A. and R. Eliassen. The removal of radioactive fallout from water by municipal and industrial water treatment plants. NYO-4441 (March 1, 1956)
- 39.\* Lowder, W. M. and L. R. Solon. Background radiation: a literature search. New York Operations Office, Health and Safety Laboratory, NYO-4712, 45 p (July 1956)
40. Maher, T. F. Nature and significance of radioactive fallout. *New Eng. J. Med.* **252**, 740-1 (1955)
41. Malone, T. F., Editor *Compendium on Meteorology*. American Meteorologic Soc., Boston (1951)
42. Martin, C. The cumulative effects of thermonuclear explosions on the surface of the earth. AEC-tr-1986; transl. from *Compt. Rend.* **239**, 1287-9 (1954)
- 43.\* Milton, G. M. and W. E. Grummitt. Radiochemical procedures for strontium and yttrium. Atomic Energy of Canada, Ltd., Chalk River Project. CRC-688 (February 1957)
- 44.\* Nishiwaki, Y. Effects of H-bomb tests in 1954. *Atom. Scientists J. (London)* **4** (5), 279-88 (1955)
- 45.\* Parker, H. M. Radiological Sciences Department research and development activities (quarterly progress report for January-March 1955). Hanford Atomic Products Operation. HW-36301
46. Perry, J. H., ed. *Chemical Engineers Handbook*, 3rd ed. p 1019 McGraw Hill Book Co. Inc., New York (1950)
47. Rand Corporation. Worldwide effects of atomic weapons. Project Sunshine. AECU-3488 (also R-251-AEC, Amended) (August 6, 1953)
- 48.\* Revelle, R., T. R. Folsom, E. D. Goldberg and J. D. Isaacs. Nuclear science and oceanography. *Geneva Conf. Proc.* **13**, 371-80 (1956)
- 49.\* Rose, H. E. Determination of the "extinction coefficient"—particle size relationship for spherical bodies. *J. Appl. Chem.* **2**, 80-88 (1952)
- 50.\* Rousseau, P. La bombe á hydrogène. *Nature (Paris)* n 3181, 136-9 (1950). *Eng. Index* **126** (1951)

- 51.\* Ruchhoft, C. C. and L. R. Setter. Application of biological methods in the treatment of radioactive wastes. *Sewage and Ind. Wastes* **25**, 48-60 (1953)
- 52.\* Sacks, J. All glass filtration apparatus for radioactive tracer experiments. *Anal. Chem.* **21**, 876-77 (1949)
53. Scheffy, W. J. Bibliography on aerosols, 1950-1955. Supl. to Report SO-1003. COO-1016, 117 p (June 1, 1956)
- 54.\* Schulz, W. W. and T. R. McKenzie. Removal of cesium and strontium from radioactive waste solutions. US A.E.C. TID 7517, 290-302 (1956)
- 55.\* Stalder, J. R., G. Goodwin and M. O. Creager. Comparison of theory and experiment for high-speed free-molecule flow. NACA Rept. 1032, formerly NACA TN 2244
56. Stone, R. S. Maximum permissible exposure standards. Geneva Conf. Proc. **13**, 132-38 (1956)
- 57.\* Strauss, L. L. The effects of high-yield nuclear explosions. U.S. Govt. Printing Office, Washington, D. C., 19 p (February 1955)
- 58.\* Strauss, L. L. Facts about radiation as they relate specifically to the atomic tests conducted in Nevada. Joint Committee on Atomic Energy. 12 p (April 15, 1955)
- 59.\* Thuronyi, G. Annotated bibliography on natural and artificial radioactivity in the atmosphere. *Meteor, Abstr.* **7** (5), 616-81 (1956)
- 60.\* United Nations. An International Bibliography on Atomic Energy, Vol. II. Scientific Aspects, Supl. II, 320 p (1953)
61. United Nations Geneva Conference. Proc. of Int. Conf. on Peaceful Uses of Atomic Energy 8/8-8/20, 1955. Vol. 7, Nuclear Chem. and Effects of Irradiation; Vol. 10, Radioactive Isotopes and Nuclear Radiation in Medicine; Vol. II, Biological Effects of Radiation; Vol. 12, Radioactive Isotopes and Ionizing Radiations in Agriculture, Physiology and Biochemistry; Vol. 13, Legal, Administrative, Health and Safety Aspects of Large Scale Use of Nuclear Energy. New York (1956)
- 62.\* University of California at Los Angeles. Atomic Energy Project quarterly progress report for period ending 3/31/54. UCLA-286
- 63.\* University of California at Los Angeles. Atomic Energy Project quarterly progress report for period ending 6/30/55. UCLA-338, 96 p (July 1, 1955)
- 64.\* University of California at Los Angeles. Atomic Energy Project quarterly progress report for period ending 3/31/56. UCLA-362 (April 1, 1956)
- 65.\* University of California at Los Angeles. Atomic Energy Project quarterly progress report for period ending 12/31/56. UCLA-386 (January 1, 1957)

- 66.\* University of Chicago, Metallurgical Laboratory. Chemical research—radiation chemistry report for month ending Oct. 31, 1944. CC-2322 (November 11, 1944)
- 67.\* University of Utah, Radiobiology Laboratory. Annual progress report AECU-3418 (March 31, 1955)
68. U.S. Army Chemical Center, Chemical and Radiological Laboratories. Aerosols. Report of Symposium V, conducted June 22 and 23, 1953, at Army Chemical Center, Chemical Corps, Maryland. NP-5065, 150 p
- 69.\* U.S. Atomic Energy Commission. Effects of high-yield nuclear explosions (with) statement by Lewis L. Strauss. U.S. Govt. Printing Office, Washington, D.C. (February 1955)
70. U.S. Atomic Energy Commission, National Defense Research Committee. Handbook on Aerosols. U.S. Govt. Printing Office, Washington, D.C. (1950)
- 71.\* U.S. Atomic Energy Commission, Division of Reactor Development. Status report on handling and disposal of radioactive wastes in the AEC program. AD 145 879 (August 1957)
72. U.S. Atomic Energy Commission, "Environmental Contamination from Weapons Tests," Health and Safety Laboratory, New York Operations Office, Report No. HASL-42, Parts A, B, C, and D June 16, 1958
73. U.S. Congress. First session on "The nature of radioactive fallout and its effects on man," Part 1, May 27, 28, 29, June 3, 1957; Part 2, June 4, 5, 6, 7, 1957; Part 3, Index, 1958. Hearings Before the Special Subcommittee on Radiation, Joint Committee on Atomic Energy
- 74.\* Veno. Research in the Effects and Influences of the Nuclear Bomb Test Explosions, Vol. I and II. Veno, Tokyo, Japan. Society for the Promotion of Sciences, 1937 p (1956)
- 75.\* Watanabe, T., *et al.* Geological study of damages caused by atomic bombs in Hiroshima and Nagasaki. Indian Minerals 9 (2), 109-17 (1955)
- 76.\* Weil, G. L. Hazards of nuclear power plants. Science 121, 315-317 (1955)
- 77.\* Wende, C.W.J. The computation of radiation hazards. AECD-3661 (January 11, 1944)

- 78.\* Wessel, W. On infinite relativistic particle matrices. Phys. Rev. 76 (10), 1512-19 (1949)
- 79.\* Wing, R. C. Potentialities of atomic warfare against the U.S. petroleum industry. U.S. Naval Inst. Proc. 75, 983-87 (1949)
- 80.\* Wolfe, R. D. Atomic defense, a constructive approach. Amer. Arva. 92(6), 29-31 (1949)
- 81. World Federation of Scientific Workers. Unmeasured Hazards. NYO-4753-S2, 40 p London (1956)
- 82.\* Yakobson, I. I. Initial radioactive investigations in Russia. Akad. Nauk Uzbek. S.S.R. 5, 118-135. (1953)

## B. FIREBALL AND CLOUD CONDITIONS

- 83.\* Balmer, M. A. and R.S. Harper. Technical photography (high speed-blast biology). Lovelace Foundation for Med. Ed. & Res. WT-1197, 25 p (December 1955)
- 84.\* Berndt, R. Physical bases of thermal nuclear reactors. Technik **12**, 547-53 (1957)
85. Bowen, I. G., A. F. Strehler and M. D. Wetherbe. Distribution and density of missiles from nuclear explosions. Lovelace Foundation for Med. Ed. & Res. WT-1168, 113 p (March 1956)
- 86.\* Brickwedde, F. G. Temperatures in atomic explosions, Vol. 2 (October 1954 Symposium). Am. Inst. Physics, p 395-412 (1955)
- 87.\* Garrigue, Hubert. Investigation of the atomic cloud. Publ. Sci. et Tech. Ministere l'Air (France), No. 228, 1-23 (1949)
- 88.\* Haber, F. On the physical process of explosive decompression. USAF School of Aviation Medicine, October 5 project report
89. Kellogg, W. W. Atomic cloud height as a function of yield and meteorology. AECU-3403, 16 p (June 14, 1956)
90. Kiseler, A. V. Basic structural types of adsorbents and their effect on the adsorption properties. Zhur. Fiz. Khim. **23**, 452-68 (1949). Nat. Res. Council of Canada Tech. Transl. TT-237 (1951)
91. Kishenevskii, M. Kh., and A. V. Pamfilev. The kinetics of absorption. Zhur. Prikladnoi Khim. **22**(11), 1173-82 (1949). A.E.R.E. transl. 11/3/5/343 (October 1953)
- 92.\* Littlechild, J. E. Products resulting from the irradiation of uranium. J. Roy. Inst. of Chem. **81**, 433-45 (1957)
93. Lotee, H. T., O. L. Mitchell and J. M. Brower. Atomic cloud sampling with rockets: development of the technique. Naval Ord. Test Station, Inyokern, Calif. NAVORD-2007, 33 p (January 13, 1953)
94. Machta, L. Entrainment and the maximum height of an atomic bomb. Bull. Am. Meteor. Soc. **31**, 215-6 (1950)
95. Mandeville, C. E. The slow neutron-induced radioactivities of nuclear explosions. J. Franklin Inst. **252**, 297-308 (1951)
96. Mandeville, C. E. Slow neutron induced radioactivities of nuclear explosions. III. J. Franklin Inst., 133-7 (1953)
- 97.\* Nottorf, R. W. Identification of strontium-90 and yttrium-90 in uranium fission. Natl. Nuclear Energy Ser. Div. IV **9** Radiochem. Studies: The Fission Products, Book 2, 682-6 (1951)
- 98.\* Pinke, A. S. Limitation of fissionable material in weapons. Bull. Atom. Scientists **13**, 177-8 (1957)

99. Rotblat, J. The hydrogen-uranium bomb. Atom. Scientists J. (London) 4(4), 224-8 (1958); Bull. Atom. Scientists 11(5), 171-2, 177 (1955)
100. Sutton, D. G. Note on "entrainment and the maximum height of atomic cloud," by L. Machta. Bull. Am. Meteor. Soc. 31, 217-18 (1950)
101. Taylor, G. The formation of a blast wave by a very intense explosion. II. The atomic explosion of 1945. Proc. Roy. Soc. A 201, 175-86 (1950)
102. U.S. Atomic Energy Commission. Thermal radiation measurement. Operation Teapot. WT-1187, 16 p (October 1956)
- 103.\* Yih, C. S. Temperature distribution in steady, laminar preheated air jet. J. Appl. Mechanics, 17(4), 381 (1950)

### C. AEROSOL FORMATION

- 104.\* Artemov, I. S. Condensation of aerosols in presence of gaseous foreign substances. *Kolloid, Zh.* **11**, 129-136 (1949). *Atm. Poll. Bull.* **19**(4), 27 (1951)
- 105.\* Asami, Tadayoshi. The growth of nuclei in the condensation of gases. *Busseiron Kenkyu* **44**, 115-18 (1951)
106. Avrami, M. Kinetics of phase change. *I. J. Chem. Phys.* **7** 1103-12 (1939)
107. Banister, J. R. and R. J. Emrich. Preliminary investigation of dust raised by blast waves (Operation Greasy Stake). Sandia Corp. Report No. SC-3610
108. Becker, R., and W. Daring. Kinetics treatment of the nucleation in supersaturated vapors. NACA TM 1374
109. Blochinzew, D. and S. Schechter. The lifespan of particles in their adsorbed state. AEC-tr-2524
110. Bradley, R. S. Nucleation in phase changes. *Quart. Revs.* **5**, 315-43 (1951)
- 111.\* Cauer, H. Chemical studies of the importance of rock particles as sublimation nuclei in the free atmosphere. *Bioklimat. Beibl.* 3-3:90-2 (1941)
- 112.\* Cauer, H. Results of chemical-meteorological research. Question of cloud formation under chemical, electrostatic and electromagnetic influences. Bioclimatic considerations. *Archiv f. Meteorologie, Geophysik u. Bioklimatologie, Ser. B I*(304):221-56 (November 1949)
113. Cernuschi, F. and H. Eyring. An elementary theory of condensation. *J. Chem. Phys.* **7**, 547-51 (1939)
114. Clay, J. and H. Van Marle. The balance of ions in the atmosphere; the production and the disappearance of ions. *Physica* **17**, 847-57 (1951)
115. Clelland, D. W., W. M. Cumming and P. D. Ritchie. Physico-chemical studies on dusts. *J. Appl. Chem. (London)* **2**, 31-48 (1952)
- 116.\* Collins, F. C. Theoretical investigation of the growth of aerosol particles by diffusion. Polytechnic Inst. of Brooklyn, Contract AF 19(122)412, Report No. 1, February 1 - April 30, 1951, 23p
117. Collins, F. C. Theoretical investigation of the growth of aerosol particles by diffusion. Polytechnic Inst. of Brooklyn, Contract No. AF 19(122)412, Final Report
- 118.\* Collins, F. C. and H. L. Frisch. Theoretical investigation of the growth of aerosol particles by diffusion. Polytechnic Inst. of Brooklyn, Contract AF 19(122)412, Quarterly report (No. 2), May 1 - July 31, 1951, 21 p



119. Corner, J. The formation of an aerosol by condensation of a dilute vapor in a carrier gas. *Proc. Roy. Soc.* **211**(A), 417-30 (March 6, 1952)
120. Correns, C.W. On the question of the stability of crystal nuclei in overheated melts and undersaturated solutions. *Naturwissenschaften* **40**, 620 (1953)
121. Cutler, W. G. and W. E. Meyer. A basic study of the physics of aerosol formation. *Pennsylvania State Univ.*, AD-87867, 239 p (July 1, 1953)
- 122.\* Dessens, H. The study of individual cloud droplet residues. *Geofis Pura e Appl.* **31**, 124-126 (1955)
123. Dixon, B. E. and J. E. L. Swallow. Use of liquid films in the study of the absorption of gases by drops. *J. Appl. Chem.* **4**, 86-93 (1954)
124. Farley, F. J. M. The theory of the condensation of supersaturated ion-free vapour. *Proc. Roy. Soc. (London)* **A212**, 530-42 (1952)
125. Frenkel, J. Statistical theory of condensation phenomena. *J. Chem. Phys.* **7**, 200-1 (1939)
126. Frenkel, J. A general theory of heterophase fluctuations and pre-transition phenomena. *J. Chem. Phys.* **7**, 538-47 (1939)
127. Frenkel, J. *Kinetic Theory of Liquids*, Chap. VII. Dover Publications, Inc., New York (1955)
- 128.\* Frisch, H. L. and F. C. Collins. Theoretical investigations of the growth of aerosol particles by diffusion. AD-3380; Report 1 (1951)
- 129.\* Frisch, H. L. and F. C. Collins. Theoretical investigation of the growth of aerosol particles by diffusion. Scientific Report No. 2. AD-32611 (1952)
130. Frisch, H. L. and F. E. Collins. Diffusional processes in the growth of aerosols. *J. Chem. Phys.* **20**, 1797-1803 (1952)
131. Frisch, H. L. and F. C. Collins. Diffusional processes in the growth of aerosol particles. II. *J. Chem. Phys.* **21**, 2158-65 (1953)
- 132.\* Fuks, N. A. Advances and practical achievements in the field of aerosols. *Uspekhi Khim.* **19**, 175-201 (1950)
- 133.\* Gendron, P. R. Studies on the mechanism of nucleation. Final Report. AFCRC-TR-54-257 (May 31, 1954)
134. Giddings, J. C. and H. Eyring. Multi-barrier kinetics. Nucleation. *J. Phys. Chem.* **62**, 305-8 (1958)
135. Glauberman, H. and A. J. Breslin. The generation of a solid submicron test aerosol. *Am. Ind. Hyg. Assoc. Quart.* **17**, 401-4 (1956)
- 136.\* Golovinskii, G. P. Condensation of a mixture of vapors under intense cooling. *Zh. Tekh. Fiz.* **26**(6), 1309-28 (1956)
- 137.\* Hass, G. Preparation and structure of thin films of silicon monoxide. CADO Tech. Data. Digest. **16**(4), 21-6 (1957)

138. Howell, W. E. The growth of cloud drops in uniformly cooled air. *J. Meteor.* 134-49 (April 1949)
139. Kantrowitz, Arthur. Nucleation in very rapid vapor expansions. *J. Chem. Phys.* **19**(9), 1097-1100 (1951)
- 140.\* Kolodner, I. I. Growth of drops by condensation. Institute of Mathematical Sciences, New York University. Report No. IMM NYU 215. AD-121 943
- 141.\* Kordes, E. Determination of the critical magnitudes for real gases and liquids, and a general equation of state for saturated vapors. *Z. Elektrochem.* **57**, 731-8 (1953)
- 142.\* Kordes, E. On a general equation of state of saturated vapours. *Naturwissenschaften* **40**, 359-60 (1953)
143. LaMer, V. K. Nucleation in phase transitions. *Ind. Eng. Chem.* **44**, 1270-7 (1952)
144. LaMer, V. K. and S. Cotson. The growth and shrinkage of aerosols. *Science* **118**, 516-7 (1953)
- 145.\* LaMer, V. K. and P. R. Gendron. Some recent advances in homogeneous aerosols. *Chemistry in Canada* **4**, 44-46 (1952)
146. Leopold, L. B. and M. H. Hatstead. First trials of the Schaefer-Langmuir dry-ice cloud seeding techniques in Hawaii. *Bull. Amer. Meteor. Soc.* **29**, 525-34 (1948)
- 147.\* Londe, A. Interaction between elementary particles. Part I. *Phys. Rev.* **76**, 1176-9 (1949)
148. Mercer, T. T. A study of some physical properties of an aerosol in relation to airborne decay products of Radon. University of Rochester (USAEC), UR-474, 115 p (March 1957)
- 149.\* Merzhanov, K. M., N. I. Peterimova and N. S. Smirnov. On the effects of air ionization on the dispersed phase of aerocolloids. *Kolloid. Zhur.* **18**, 574-7 (1956)
- 150.\* Oak Ridge National Laboratory. Protective equipment evaluation program. Quarterly report for July 1, 1951 to September 30, 1951. ORNL-1352 (August 6, 1952)
151. Ogiwara, S. and T. Okita. Electron-microscope study of cloud and fog nuclei. *Tellus* **4**, 233-40 (1952)
- 152.\* O'Konski, C. T. Kinetics of gas-phase nucleation. Office of Naval Research, Chemistry Branch, Contract No. ONR-222-12, Project No. NR 051-302. Final Report, January 1, 1958
153. Orr, Clyde, Jr., K. E. Hurd, *et al.* An investigation into the growth of small aerosol particles with humidity changes. AD-110 275. AFCRC-TR-57-253

154. Orr, J. L., D. Fraser and K. G. Pettit. Canadian experiments on artificially inducing precipitation. *Bull. Amer. Meteor. Soc.* **31**(2), 56-9, (1950)
- 155.\* Perrie, D. W. *Cloud Physics*. John Wiley & Sons, New York, 119 p (1950)
- 156.\* Petrygnov, I. V. and N. N. Tunitskii. Formation of aerosols during the condensations of supersaturated vapors. *J. Phys. Chem. (USSR)* **13**, 1131-40 (1939)
157. Probstein, R. F. Time lag in the self-nucleation of a supersaturated vapor. *J. Chem. Phys.* **19**, 619-26 (1951)
158. Pound, G. M. Liquid and crystal nucleations. *Ind. Eng. Chem.* **44**, 1278-83 (1952)
159. Reiss, H. The statistical mechanical theory of irreversible condensation. I. *J. Chem. Phys.* **20**, 1216-27 (1952)
160. Reiss, H. Theory of the liquid drop model. *Ind. Eng. Chem.* **44**, 1284-88 (1952)
- 161.\* Rodebush, W. H. Nuclei in evaporation and condensation. *Chem. Rev.* **44**, 269-76 (1949)
162. Rodebush, W. H. Spontaneous nucleation in supersaturated water vapor. *Ind. Eng. Chem.* **44**, 1289-91 (1952)
- 163.\* Sagalyn, R. C. and G. Faucher. Investigation of charged nuclei in the free atmosphere. *Geofis. Pura e Appl.* **31**, 182 (1955)
164. Schaefer, V. J. Formation of ice crystals in ordinary and nuclei-free air. *Ind. & Eng. Chem.* **44**, 1300-4 (1952)
165. Squires, P. The growth of cloud drops by condensation. I and II. *Australian J. Sci. Res., A*, **5**, 59-86, 473-99 (1952)
166. Stewart, K. Condensation of vapour to assembly of droplets or particles. *Trans. Farad. Soc.* **52** 398, 161-73 (1956)
167. Tohmfor, G. and M. Volmer. Nuclei formation under influence of an electric potential. *Ann. Physik* **33**, 109-31 (1938)
168. Tolman, R. C. The effect of droplet size on surface tension. *J. Chem. Phys.* **17**, 333-7 (1949)
169. Turnbull, D. and B. Vonnegut. Nucleation catalysis. *Ind. Eng. Chem.* **44**, 1292-98 (1952)
- 170.\* University of Chicago, Department of Meteorology. Cloud physics research. Final report under Contract No. AF 19(604)-618, 32 p (January 31, 1956)
- 171.\* Volmer, M. *Kinetik der Phasenbildung*. T. Steinkopff, Dresden, 1939
- 172.\* Vonnegut, B. Nucleation of supercooled water clouds by silver iodide smokes. *Chem. Rev.* **44**, 277-89 (1949)

- 173. Werle, D. K. and C. R. McCully. The formation of metallic aerosols  
AD-53 468. A.R.F. Scientific Report No. 17
- 174.\* Wigener, P. and R. Smelt. Naval Ordnance Laboratory Memorandum 10772  
(15 February 1950)
- 175.\* Witten, L. A generalization of Yang and Lee's theory of condensation.  
Phys. Rev. **93**, 1131-5 (1954)

#### D. DEPOSITION AND RETENTION ON SURFACES

176. \* Anonymous. Research on Collision Processes in Gases. Department of Physics, Syracuse University. AD-50469. Progress Report, 1 October - 31 December 1954
177. \* Amelin, A. G. The question of applying poisons in the form of aerosols. Doklady Vsesoiuznoi Ardena Lenina Akademii Sel'skokhozeastrennykh. Nauk imeni. V. I. Lenina, **16**(8), 34-38 (1951)
178. \* Amelin, A. G. and Z. B. Borodastova. Theory of the process of separation of vapor by freezing out. Zhur. Fiz. Khim. **24**, 529-33 (1950)
179. \* Asset, G., L. E. Gongwer and S. Ryan. Nasal penetration of particles of small inertia in experimental animals. Arch. Ind. Health **13**, 597-601 (1956)
180. Asset, G. and D. Pury. Deposition of wind-borne particles on human skin. Arch. Ind. Hyg. & Occup. Med. **9**(5), 273-83 (1954)
181. Best, A. C. The size distribution of raindrops of rain. Quarterly, J. Roy. Meteorol. Soc. (London) **76**, 16-36 (1950)
182. Blasewitz, A. G. and B. F. Judson. Filtration of radioactive aerosols by glass filters. Air Repair **4**, 223-9 (1955)
183. Blifford, I. H., L. B. Lockhart, Jr. and R. A. Baus. Relationship between the air concentration of radioactive fission products and fallout. NRL-4607 (August 20, 1955)
184. Bonch-Bruevich, B. L. Quantum theory of adsorption. Uspekhi. Fiz. Nauk **40**(3), 369-406 (1950); Nat. Res. Council of Canada Tech. Transl. TT - 509 (1954)
185. Brescia, F. Salt marsh and anopheline mosquito control by ground dispersal of DDT aerosols. J. Econ. Entomol. **39**(6), 698-715 (1946)
186. Brittain, R. W. and W. M. Carleton. How surfaces affect pesticidal dust deposition. Agricul. Engin. **37**, 22-25, 31 (1957)
187. Brown, C. E. Quantitative measurements of the inhalation, retention and exhalation of dusts and fumes by man II. Concentrations below 50 mg per cm. m. J. Ind. Hyg. & Toxicol. **13**, 285-91 (1931)
188. Brown, J. H., K. M. Cook, F. G. Ney and T. Hatch. Influence of particle size upon the retention of particulate matter in the human lung. Am. J. Pub. Health **40**(4), 450-58, 480 (1950)
189. \* Brown, W. B. and S. G. Heuser. Behavior of fumigants during vacuum fumigation. I. Penetration of methyl bromide into boxes of dates. J. of Sci. of Food and Agr. **4**, 48-57 (1953)
190. \* Brun, R. J. and R. G. Dorsch. Impingement of water droplets on an ellipsoid with fineness ratio 10 in axisymmetric flow. NACA TN 3147

- 191.\* Brun, R. J., H. M. Gallagher and D. E. Vogt. Impingement of water droplets on NACA 65, - 208 and 65, - 212 airfoils at 4° angle of attack. NACA TN 2952
- 192.\* Brun, R. J., H. M. Gallagher and D. E. Vogt. Impingement of water droplets on NACA 65 A004 airfoil and effect of change in airfoil thickness from 12 to 4 percent at 4° angle of attack. NACA TN 3047
- 193.\* Brun, R. J., H. M. Gallagher and D. E. Vogt. Impingement of water droplets on NACA 65 A004 airfoil at 8° angle of attack. NACA TN 3155
- 194.\* Brun, R. J., J. S. Serafini and G. J. Mashos. Impingement of water droplets on an NACA 65, - 212 airfoil at an angle of attack of 4°. NACA RM E52 B12
- 195.\* Brun, R. J., W. Lewis, P. J. Perkins and J. S. Serafini. Impingement of cloud droplets on a cylinder and procedure for measuring liquid-water content and droplet sizes in supercooled clouds by rotating multicylinder method. NACA Rept. 1215
- 196.\* Brun, R. J. and D. E. Vogt. Impingement of water droplets on NACA 65 A004 airfoil at 0° angle of attack. NACA TN 3586
197. Brunskill, R. T. Physical factors affecting the retention of spray droplets on leaf surfaces. Brit. Weed Control Conf. Proc. 3(2), 593-603 (1956)
198. Burnett, G. F. and B. W. Thompson. Aircraft applications of insecticides in East Africa. X. An investigation of the behavior of coarse aerosol cloud in woodland. B. Ent. Res. 47, 495-524 (1956)
199. Byrdy, W., K. Gorecki and A. Kolodziejczyk. Investigation of adhesion of powder and liquid agents on plant protection by washing and blowing off. Przem. Chem. 13(6), 351-3 (1957)
200. Cannon, G. Are spray chemicals too hot to handle. Farm Quarterly 9, 45-47, 90-94 (Summer 1954)
- 201.\* Chadwick, R. C. and A. C. Chamberlain. The maximum permissible level of iodine-131 over grassland. Atom. Energy Res. Estab. (Brit.), AERE-HP/M-24, 9 p (May 28, 1951)
- 202.\* Chamberlain, A. C. Experiments on the deposition of iodine-131 vapor onto surfaces from an air stream. Gr. Brit. AERE-HP/R-1082 (1952)
203. Chamberlain, A. C. Aspects of travel and deposition of aerosol and vapor clouds. A.E.R.E. Rep. No. HP/R 1261, 35 p (1955)
204. Chamberlain, A. C. and R. C. Chadwick. Deposition of airborne radioiodine vapor. Nucleonics 11(8), 22-25 (1953)
205. Chamberlain, J. C., et al. Studies of airplane spray-deposit patterns at low flight levels. U.S. Agr. Tech. Bull. 1110, 1-45 (1955)

- 206.\* Cockburn, R. The analogy between heat transfer and the deposition of solid fission products. Gr. Brit. AERE-NM/9 (1948)
207. Collins, W. E. The effectiveness of pyrethrum and allethrin formulations in a thermal fog machine. J. Econ. Entom. **49**, 610-1 (1956)
208. Comar, C. L., R. S. Russell and R. H. Wasserman. Strontium-calcium movement from soil to man. Science **126**, 485-92 (1957)
209. Coner, J. and E. D. Pendlebury. The coagulation and deposition of a stirred aerosol. Proc. Phys. Soc. **64B**, 645-54 (1951)
- 210.\* Courshee, R. J. Developments in drift spraying. World Crops **5**, 109-11, 119 (1953)
- 211.\* Dallavalle, J. M., C. Orr, Jr. and B. L. Hinkle. Investigation of aggregation of fine particle matter suspended in air. AD-766; Quarterly Report 6 (December 14, 1956)
- 212.\* Daniels, G. C. Prevention of turbine-blade deposits. ASME Paper No. 48-SA-25. Mech. Eng. 694-5 (August 1948)
213. Das, P. K. The growth of cloud droplets by coalescence. Indian J. Meteor. & Geophys. **1**(2), 137-144 (1950)
214. Dautrebande, L., *et al.* Coating and agglutination of dust by aqueous aerosols. Jour. Ind. Hyg. & Toxicol. **30**, 108-13 (1948)
215. Davies, C. N. Physics of airborne dust. Heat. & Vent. Eng. **26**, 52-60 (1952)
216. Deonier, C. E. Penetration of the foliage canopy of corn and potatoes by aerial spray. J. Econ. Entom. **48**, 629 (1955)
- 217.\* Devienne, Marcel. Condensation and adsorption of molecules on a surface in rarefied atmosphere. Mem. Sci. Phys. **53**, 1-86 (1952)
- 218.\* Dorman, S. C. and W. E. Hall. Improved spray tunnel method for laboratory tests. J. Econ. Entom. **46**, 151-3 (1953)
- 219\* Dorsch, R. G. and R. J. Brun. A method for determining cloud-droplet impingement on swept wings. NACA TN 2931
- 220.\* Dorsch, R. G., R. J. Brun and J. L. Gregg. Impingement of water droplets on ellipsoid with fineness ratio 5 in axisymmetric flow. NACA TN 3099
- 221.\* Dorsch, R. G., P. G. Soper and C. F. Kadow. Impingement of water droplets on a sphere. NACA TN 3587
- 222.\* Drozin, V. G. and D. C. Hochberg. Filtration of monodisperse solid aerosols. Progress Report for September 1, 1953 - August 31, 1954. NYO-4603 (August 31, 1954)
223. Farlow, N. H. and W. R. Schell. Physical, chemical and radiological properties of slurry particulate fallout collected during Operation Redwing. Naval Radiological Defense Laboratory, San Francisco. Project Ns 088-001. NRDL-TR-170, 19 p, May 5, 1957

224. Farrar, M. D. and J. K. Reed. Methods for evaluation of cotton insecticides. *J. Econ. Entom.* **44**, 943-5 (1951)
225. Fortak, H. Dust transport over dusty surfaces. *Z. Meteor.* **11**(1), 19-27 (1957)
226. Freed, S. and M. L. Schultz. Deposition of atmospheric radioactivity on objects exposed to air streams. *J. Franklin Inst.* **231**(4), 345-55 (1951)
227. Friedlander, S. K. Deposition of aerosol particles from turbulent gases. Univ. Microfilms Publ. No. 10,476, 84 p
228. \* Gelder, T. F., W. H. Smyers, Jr., and U. Von Glahn. Experimental droplet impingement on several two-dimensional airfoils with thickness ratios of 6 to 16 percent. NACA TN 3839
229. Gillespie, I. T. The adhesion of drops and particles on impact at solid surfaces. *J. Colloid. Sci.* **10**, 266-80 (1955)
230. \* Gillespie, T. and G. O. Langstroth. Coagulation and deposition in still aerosols of various solids. *Can. J. Chem.* **20**, 1003-11 (1952)
231. Gillespie, T. and E. Rideal. On the adhesion of drops and particles on impact at solid surfaces. *J. Colloid. Sci.* **10**, 281-98 (1955)
232. Gordieyeff, V. A. Adsorption of gases and vapors on aerosol particulates. *Am. Ind. Hyg. Assoc. Quart.* **17**, 411-17 (1956)
233. \* Gordieyeff, V. A. Adsorption of vapors on solid aerosols (dusts). AD-107 915. Rept. No. CWLR 2051
234. \* Gordieyeff, V. A. Absorption of vapors by liquid aerosols. AD-107 916 Rept. No. CWLR 2052
235. Gordieyeff, V. A. Toxicity of vapors in the presence of aerosol carriers. Chemical Warfare Laboratory, Army Chemical Center, Md. CWLR-2053 (August 17, 1956)
236. Goodhue, L. D. Aerosols and their application. *J. Econ. Entom.* **39**(4), 506-9 (1946)
237. Greenfield, S. M. Ionization of radioactive particles in the free air. *J. Geophys. Res.* **61**(1), 27-33 (1956)
238. Greenfield, S. M. Rain scavenging of radioactive particulate matter from the atmosphere. *J. Meteor.* **14**(2), 115-25 (1957)
239. Gregg, S. J. Phase changes in adsorbed films at the gas/solid interface. Research Supl., Surface Chemistry, 205-16 (1949)
240. Gregory, P. H. Deposition of airborne lycopodium spores on cylinders. *Ann. Appl. Biol.* **38**(2), 357-76 (1951)
241. \* Guibert, A. G., E. Janssen and W. M. Robbins. Determination of rate area, and distribution of impingement of waterdrops on various airfoils from trajectories obtained on the differential analyzer. RM 9 A05



242. \* Gurei, S., S. G. Ward and R. L. Whitmore. Studies of the viscosity and sedimentation of suspensions. III. The sedimentation of isometric and compact particles. Br. J. Appl. Phys. **6**, 83-7 (1955)
243. \* Hacker, P. T., R. J. Brun and B. Boyd. Impingement of droplets in 90° elbows with potential flow. NACA TN 2999
244. \* Hacker, P. T., P. G. Soper and C. F. Kadow. Impingement of droplets in 60° elbows with potential flow. NACA TN 3770
245. Harris, B. L. Adsorption. Ind. Eng. Chem. **47**, 508-17 (1955)
246. \* Harwit, M. O. Deposition of airborne particles on a large heated surface. AD-107913. Report No. CWLR 2046
247. \* Harwit, M. O. Subsidence of a column of airborne particles. AD-99187. Tech. Rept. No. CWLR 2039
248. \* Hatch, T. F. Behavior of microscopic particles in the air and in the respiratory system. Symposium on Aerobiology. Am. Assoc. Adv. Sci., ser. 17, (1942)
249. \* Hedden, O. K. and D. A. Isler. Airplane spray and dust applications. SAE Preprint No. 415, 9-13 (January 1950)
250. Helvey, T. C. Dissemination of airborne particles by explosives. World Health Organ. B. **16**(1), 225-7 (1957)
251. Hinkle, B. L. and C. Orr, Jr. Electrification in aerosol studies. Res. Engineer, 7-8, 19-21 (March 1952)
252. \* Hocking, K. S. and D. Yeo. Aircraft application of insecticides in East Africa. XI. Applications of a coarse aerosol to control *Glossina morsitans* Westw. at Urambo, Tanganyika, and *G. morsitans* Westw. and *G. pallipedes* Aust. in Lango County, Uganda. B. Ent. Res. **47**, 631-44 (1956)
253. Hooper, W. J. The deposition of dust on walls. Physics **1**(1), 61-8 (1931)
254. Hopkins, L., *et al.* Persistence of insecticide residues on forage crops. J. Econ. Entom. **45**, 213-18 (1952)
255. \* Hopkins, L., G. G. Gyrisco and L. B. Norton. Effects of sun, wind and rain on DDT dust residues on forage crops. J. Econ. Entom. **45**(4), 629-33 (1952)
256. \* Hurtig, H., *et al.* New technique for sampling and assessing aerial spray deposits. Can. J. Agr. Sci. **36**, 81-94 (1956)
257. Ingebo, R. D. Drag coefficients for droplets and solid spheres in clouds accelerating in airstreams. NACA TN 3762
258. \* Isler, D. A. and D. G. Thornton. Effect of atomization on airplane spray patterns. Agr. Eng. **36**, 600-1 (1955)
259. \* Isler, D. A. and J. S. Yuill. Research on the control of forest insects by aircraft. J. Econ. Entom. **49**, 92-4 (1956)

260. Johnstone, H. F. and M. H. Roberts. Deposition of aerosol particles from moving gas streams. *Ind. Eng. Chem.* **41**, 2417-22 (1949)
261. Johnstone, H. F., W. E. Winsche and L. W. Smith. The dispersion deposition of aerosols. *Chem. Rev.* **44**, 353-71 (1949)
- 262.\* Jordan, D. W. The adhesion of dust particles. The physics of particle size analysis. 194-97, disc. 197-8. *Br. J. Appl. Phys.* Supl. No. 3. Inst. of Physics, London, 1954
263. Kiselev, A. V. Basic structural types of adsorbents and their effect on the adsorption properties. TT-237; AEC-tr-979 (Transl. from *Zhur. Fiz. Khim.* **23**, 452-68 (1949))
- 264.\* Kishinevskii, M. Kh. The kinetics of absorption. AERE-Trans-11/3/5/343 [Transl. from *Zhur. Priklad. Khim.* **22**, 1173-82 (1949)]
265. Klechkovsky, V. M., ed. On the behavior of radioactive fission products in soil. Their absorption by plants and their accumulation in crops. USAEC, 1957, 2274 (QC 790 Ak 130). Washington, D.C.
266. Kogan, Y. I. and R. S. Repina. An effect in the motion of aerosol particles. *Dokl. Akad. Nauk SSSR* **111**, 851-4 (1956)
267. LaBelle, C. W., *et al.* Synergistic effects of aerosols. Particulates as carriers of toxic vapors. *Arch. Ind. Health* **11**, 297-304 (1955)
- 268.\* LaMer, V. K. A note on deposition of aerosols. U.S. Air Force, Cambridge Research Center, *Geophys. Res. Papers* No. 13, 73-76 (May 1952)
269. LaMer, V. K., S. Hochberg, K. Hodges, I. Wilson, J. A. Fales and R. Latta. The influence of particle size of homogeneous insecticidal aerosols on the mortality of mosquitos in confined atmospheres. *J. Colloid. Sci.* **2**(6), 539-49 (1947)
270. LaMer, V. K. and S. Hochberg. The laws of deposition and the effectiveness of insecticidal aerosols. *Chem. Revs.* **44**(2), 341-52 (1949)
271. Landahl, H. D. and S. Black. Penetration of air-borne particulates through the human nose. *J. Ind. Hyg. Toxicol.* **29**, 269-77 (1947)
272. Landahl, H. D. and R. G. Hermann. Retention of air-borne particles in human beings. *J. Ind. Hyg. & Toxicol.* **30**, 181-8 (1948)
273. Landahl, H. D. and R. G. Hermann. Sampling of liquid aerosols by wires, cylinders and slides, and the efficiency of impaction of the droplets. *J. Colloid. Sci.* **4**, 103-36 (1949)
274. Latta, R. Field experiments with heat-generated aerosols. *J. Econ. Entom.* **39**(5), 614-9 (1946)
275. Latta, R., L. D. Anderson, E. E. Rogers, V. K. LaMer, S. Hochberg, H. Lauterbach and I. Johnson. The effect of particle size and velocity of movement of DDT aerosols in a wind tunnel on the mortality of mosquitoes. *J. Wash. Acad. Sci.* **37**(11), 397-407 (1947)

276. Lepingle, M. Dusts and aerosols. Bull. Soc. Franc. Ceram. 7, 48 (1950)
277. Levich, V. G. Theory of coagulation and settling of aerosols in turbulent gas flow. Removal coefficient for aerosol particles. Dokl. Akad. Nauk SSSR 99, 1041-4 (1954)
278. Levin, L. M. The coagulation of charged cloud-drops. Dokl. Akad. Nauk SSSR, 94(3), 467-70 (1954)
- 279.\* Lewis, W. and R. J. Brun. Impingement of water droplets on a rectangular half body in a two-dimensional incompressible flow field. NACA TN 3658
280. Machta, T. Meteorological factor affecting spread of radioactivity from nuclear bombs. J. Wash. Acad. Sci. 47, 169-79 (1957)
281. McBride, E. E. An experimental investigation of the scale relations for the impinging water spray generated by a planing surface. NACA TN 3615
282. McCampbell, J. M. Cascade filtration theory: a basis for studying suspended particles. USNRDL-TR-61 (April 19, 1955)
283. McCool, J. C. Insecticidal performance of Strobane aerosols as a function of particle size and formulation of sprays. Chem. Spec. Mfr. Assoc., Proc. Ann. Mtg. 43, 41-4 (1956)
284. McCully, C. R., M. Fisher, G. Langer, J. Rosinski, H. Glaess and D. Werle. Scavenging action of rain on air-borne particulate matter. Ind. Eng. Chem. 48, 1512-16 (1956)
285. Meetham, A. R. Natural removal of pollution from the atmosphere. Roy. Met. Soc. Q. J. 76(330), 359-71 (1950)
286. Meetham, A. R. Natural removal of atmospheric pollution during fog. Roy. Met. Soc. Q. J. 80(343), 96-99 (1954)
- 287.\* Milligan, W. O. and G. S. Mill. Colloids and surface behavior. Ind. Eng. Chem. 47, 614-25 (1955)
- 288.\* Moore, J. W., et al. A new instrument for measuring the sorptive capacities of various pesticide carriers. Agr. Chem. 12; 51 (1957)
- 289.\* Morken, D. A. and P. E. Morrow. Control and measuring system on an apparatus for the study of respiratory tract retention. US AEC Doc. (Rochester Univ.), Contract W-7401-eng-49 (1955)
- 290.\* Orr, C., Jr., M. T. Gordon and J. B. Garrett. Investigations of factors determining aggregation of fine-particle matter. Quarterly Report No. 3. AD-44577 (March 14, 1954)
291. Orr, C., Jr., M. T. Gordon and J. B. Garrett. An investigation of factors determining aggregation of fine-particle matter. Final Report. AD-38787 (June 14, 1954)

292. Pace, E. L., K. S. Dennis, S. A. Greene and E. L. Heric. Reversibility in physical adsorption. *Can. J. Chem* **33**, 245-50 (1955)
- 293.\* Percy, T. and G. W. Hill. A theoretical estimate of the collection efficiencies of small droplets. *Quart. J. Roy. Meteor. Soc.* **83**(355), 77-92 (1957)
294. Perring, J. K. The theory of physical adsorption. Part. I. Thermodynamics. AERE-C/R-1055 (November 3, 1952)
295. Potts, S. F. Particle size of insecticides and its relation to application, distribution and deposit. *J. Econ. Entom.* **39**(6), 716-20 (1946)
296. Ranz, W. E. Impaction of aerosol particles on cylindrical and spherical collectors. Tech. Rept. 3 (SO-1004), 92 p (1952)
297. Remy, H. Aerosol properties and factors affecting them. Staub, 429-42 (December 15, 1951)
298. Rich, S. Dynamics of deposition and tenacity of fungicides. *Phytopathology* **44**, 203-13 (1954)
299. Richardson, J. F. and W. N. Zaki. The sedimentation of a suspension of uniform spheres under conditions of viscous flow. *Chem. Eng. Sci.* **3**, 65-73 (1954)
- 300.\* Ritter, H. L. and L. C. Erich. Pore size distribution in porous material. *Anal. Chem.* **20**, 665-70 (1948)
301. Rosinski, J. Efficiency of scavenging devices used in determining fallout. Scientific report No. 1. AECU-3486, 130 p (January 25, 1957)
302. Rosinski, J. Efficiency of scavenging devices used in determining fallout. AECU-3435 (Armour Research Foundation) Progress report No. 5, Feb. 1 to March 15, 1957
303. Rosinski, J. Efficiency of scavenging devices in determining fallout. AECU-3547 (Armour Research Foundation), 40 p (September 23, 1957)
304. Rounds, W., Jr. Solutions of the two-dimensional diffusion equations. *Trans. Am. Geophysical Union* **36**(3), 395-405 (1955)
305. Sack, R. A. A modification of Smoluchowski's diffusion equation. *Physics* **22**, 917-8 (1956)
- 306.\* Saffman, P. G. and J. S. Turner. On collision of drops in turbulent clouds. *J. Fluid Mech.* **1**, 16-30 (1956)
307. Scheffy, W. J. Properties of aerosol agglomerates. TID-7513 (Part 1), 292-305 (November 1955)
308. Seidenberg, J. Z. Method of measuring the concentration and the particle size of natural aerosols. *Compt. Rend. Acad. Sci. URSS* **46**, 227-8 (1945)

309. \* Serafini, J. S. Impingement of water droplets on wedges and double-wedge airfoils at supersonic speeds. NACA Rept. 1159, (formerly TN 2971) (1954)
310. Smith, M. E. and I. A. Singer. Diffusion and deposition in relation to reactor safety problems. Am. Ind. Hyg. Assoc. Quart. **18**(4), 319-30 (1957)
311. Somers, E. Studies of spray deposits. III. Factors influencing the level of "run-off" deposit of copper fungicides. J. Sci. Food & Agr. **8**, 520-6 (1957)
312. Somers, E. and W. D. E. Thomas. Studies of spray deposits. II. The tenacity of copper fungicides on artificial and leaf surfaces. J. Sci. Food & Agr. **7**, 655-67 (1956)
313. Stewart, N. G., R. G. D. Osmond, R. N. Crooks and E. M. Fisher. The world-wide deposition of long-lived fission products from nuclear test explosions. Gt. Brit. AERE-HP/R-2354(October 1957)
314. Stokinger, H. E. Air pollution and the particle size toxicity problem. I. Nucleonics **5**, 50, 62 (1949)
315. \* Tang, Y. S., J. M. Duncan and H. E. Schweyer. Heat and momentum transfer between a spherical particle and air stream. NACA TN 2867
316. \* Thornton, D. G. and J. M. Davis. Method of sampling for the drop size of aerial spray deposits. J. Econ. Entom. **49**, 80-3 (1956)
317. Thomas, J. W. and R. E. Yoder. Aerosol size for maximum penetration through fiberglas and sand filters. Arch. Ind. Health **13**, 545-9 (1956)
318. Tunitskii, N. N. and I. V. Petryanov. On the theory of aerosol filtration. I. The role of Van der Waal's forces. AEC-tr-1843 [Transl. from Zhur. Fiz Khim. **17**, 408-13 (1943)]
319. \* U. S. Federal Civil Defense Administration. Fallout debris deposition. U. S. Govt. Printing Office. FCD 1.3:11-31, 1957
320. \* Von Glahn, U. H., T. F. Gelder and W. H. Smyers, Jr. A dye-tracer technique for experimentally obtaining impingement characteristics of arbitrary bodies and a method for determining droplet size distribution. NACA TN 3338
321. Van Wijk, A. M. and H. S. Patterson. The percentage of particles of different sizes removed from dust-laden air by breathing. J. Ind. Hyg. Toxicol. **22**, 31-35 (1940)
322. \* Wahlgreen, M. A. and W. W. Meinke. Molecular sieves adsorb  $I^{131}$  from air. Nucleonics **15**, 156, 158, 160 (1957)
323. Wilson, I. B. Deposition of charged particles in tubes, with reference to retention of therapeutic aerosols in human lung. J. Colloid. Sci. **2**, 271 (1947)

324. Wilson, I. B. and V. K. LaMer. The retention of aerosol particles in the human respiratory tract as a function of particle radius. *J. Ind. Hyg. Toxicol.* **30**, 265-80 (1948)
325. \* Woesner, R. H. and R. Gunn. Measurements related to the fundamental processes of aerosol electrification. *J. Colloid.* **11**(1), 69-76 (1956)
326. Wong, J. B., W. E. Ranz and H. F. Johnstone. Inertial impaction of aerosol particles on cylinders. *J. Appl. Phys.* **26**, 244-9 (1955)
327. Wooding, E. R. Concentration changes in an aerosol. *Proc. Phys. Soc. B.* **70**, Pt. 1, 65-70 (1957)
328. Wright, T. E., R. J. Stasny and C. E. Lapple. High velocity air filters. WADC Tech. Rept. 55-457 (AD-142075) (October 1957)
329. Yano, M. and H. Naruse. Radioactive dust in the air. *Papers Meteor. and Geophys.* (Tokyo) **7**(1), 34-41 (1956)
330. Yeo, D. and B. W. Thompson. Deposition of a coarse aerosol released from a low flying aircraft. *Nature* **172**(4369), 168-9 (July 25, 1953)
331. \* Yeomans, A. H. and E. E. Rogers. Factors influencing deposit of spray droplets. *J. Econ. Entom.* **46**, 57-60 (1953)
332. Yeomans, W. H., E. E. Rogers and W. H. Ball. Deposition of aerosol particles. *J. Econ. Entom.* **42**, 591-6 (1949)
333. \* Yates, W. E. and N. B. Akesson. Research studies of spray drift from agricultural aircraft. *Calif. Weed Conf. Proc.* **8**, 135-7 (1956)
334. \* Yoshiyasu, F. Research into the properties of aerosols - adhesion of minute particles to glass surfaces. AD 78 745. Trans. No. TIB/T4517 from J. Chem. Soc. Japan

## E. ATMOSPHERIC TRANSPORT, DISTRIBUTION, AND SUBSIDENCE

- 335.\* Anonymous. A-bomb fallout studied. *Sci. News Letter* **70**, 156 (Sept. 10, 1956)
336. Anonymous. Analysis of the "Bikini ash." AEC-tr-2104. (Transl. from *Japan Analyst* **3**, 333-68 (1954)
337. Anonymous. A study of the atmosphere between 30,000 feet and 100,000 feet. AD-79651. Report No. 3 NAVAER-50-IR-224B
338. Anonymous. Committee on Meteorological Aspects of the Effects of Atomic Radiation. Meteorological aspects of atomic radiation. *Science* **124**, 105-12 (1956)
339. Anonymous. "Dirt" from "clean" bombs. *Sci. News Letter* **72**, 3 (1957)
340. Anonymous. Fallout patterns. *Sci. News Letter* **69**(3) (1956)
- 341.\* Anonymous. Oceanography, fisheries, and atomic radiation. *Science* **124**, 13-6 (1956)
342. Anonymous. Radioactive fallout in Great Britain. *Science* **122**, 234 (1955)
343. Anonymous. Hq. Air Weather Service MATS USAF. Radioactivity fallout plots. AD-52-761. Air Weather Service Manual No. 105-33
344. Abribat, M., *et al.* Artificial radioactivity in rainwater of the Paris area. *Compt. Rend.* **234**, 1161-3 (1952)
345. Abribat, M., *et al.* Artificial radioactive products in the atmosphere at Paris. *Compt. Rend.* **235**, 157-9 (1952)
346. Abribat, M. and J. Pouradier. Evolution of the amount of artificial radioactive elements in the atmosphere of Paris. *Compt. Rend.* **237**, 1233-55 (1953)
347. Abribat, M., J. Pouradier and A. M. Venet. Evolution of atmospheric radioactivity in the Paris region. *Compt. Rend.* **240**(24), 2310-12 (1955)
- 348.\* Adams, C. E., N. H. Farlow and W. R. Schell. Nature of radioactive fallout particles. Presented to A.C.S. 132nd Mtg., New York, N.Y. (September 8-13, 1957) (also USNRDL-TR-209, February 3, 1958)
349. Akpinar, S. Rapid method for dating nuclear explosions. *Nucleonics* **15**, 88-9 (1957)
- 350.\* Akpinar, S. and R. Akpinar. Radioactive precipitation in Istanbul and Vludag (Turkey). *Rev. Fac. Sci. Univ. Istanbul* **20c**, 287-302 (1955)
- 351.\* Alba, A. F., V. Beltran, T. A. Brody, H. Lezama, A. Moreno, M. A. Tejera and B. M. Vasquez,. Preliminary information on studies of radioactive rain. *Rev. Mex. Fis.* **5**, 153-66 (October 1956)

- 352.\* Alba, F., T. A. Brody, H. Lezama, A. Tejera and M. V. Barete. Second report on radioactive precipitation. *Rev. Mex. Fis.* **6**, 97-104 (1957)
- 353.\* Alexander, G. V., R. E. Nusbaum and N. S. MacDonald. Strontium and calcium in municipal water supplies. *J. Am. Wtr. Wrks. Assoc.* **46**(7), 643-54 (1954)
- 354.\* Aliverti, G. and G. Lovera. The effect of some meteorological elements on the diffusion of radon in the telluric atmosphere. AEC-tr-2858. *Trans. from Ann. Geofis. (Rome)* **2**, 92-102 (1949)
- 355.\* Allen, J. S. A-bomb fallout in northern West Virginia. *W.Va. Univ. Bull. Ser.* **56**, 55-7 (1955)
- 356.\* Amelin, A.G. The formation of radiation clouds. *Dokl. Akad. Nauk SSSR* **77**, 249-52 (1951)
- 357.\* Anderson, A. D. Free-atmospheric turbulence, Naval-Research Laboratory Report No. 4735; AD-99726
- 358.\* Anderson, O. K. Meteorological aspects of air pollution control. *Combustion* **24**(7), 52-5 (January 1953)
- 359.\* Arizumi. On the distribution of ash-fall (meteorological investigation on the H-bomb experiment at Bikini Is. II). *J. Meteor. Soc. Japan* **32**(9-10)(1954)
- 360.\* Armour Research Foundation. A field study on the scavenging of dust by rain. Contract AF 19(122)-472, Proj. CO22. Scientific Rept. No. 15, Oct. 26, 1954
361. Bandopadhyay, K. G., *et al.* Radioactive nuclei in rains over Calcutta. *Science and Culture (Calcutta)* **21**(5), 273-5 November 1955)
- 362.\* Barreivia, F. and Laranjeira. Determination of atmospheric radioactivity ( $\beta$  activity). *Rev. Fac. Aênc. Univ. of Lisbon. 2a Sér.* **B4**, 23-46(1955)
363. Baumash, L., J. W. Neel and R. F. Butts. The effect of Pacific weapons testing on background activities in the State of California. UCLA-388 (May 14, 1957)
364. Bell, C. G., Jr. Sanitary engineering aspects of long-range fallout from nuclear detonations. NYO-4654, 248 p (January 1955)
365. Bell, C. G., H. A. Thomas and B. L. Rosenthal. Passage of nuclear detonation debris through water treatment plants. *J. Am. Wtr. Wrks. Assoc.* **46**, 973-86 (1954)
366. Blifford, I. H. Total radioactive fallout. *Sci. News Letter* **69**(17), 267 (April 28, 1956)
- 367.\* Beers, N. R. Stack meteorology and atmospheric disposal of radioactive waste. *Nucleonics* **4**, 28-38 (1949)



- 368.\* Bergrun, N. R. An empirically derived basis for calculating the area, rate, and distribution of water drop impingement on airfoils. NACA 1107
- 369.\* Bergrun, N. R. An empirical method permitting rapid determination of the area, rate, and distribution of water-drop impingement on an airfoil of arbitrary section at subsonic speeds. NACA TN 2476
- 370.\* Bergrun, N. R. Numerically calculating the area and distribution of water impingement on the leading edge of an airfoil in a cloud. NACA TN 1397
- 371.\* Besson, A. and T. Pelletier. Radioactivity and air pollution. Bull. Acad. Natl. Med. (Paris) **140**, 43-5 (1956)
- 372.\* Best, A. C. Maximum concentration at ground level of gas from a heated elevated source. Meteor. Mag. **84**(1000), 297-300 (1955)
- 373.\* Bigg, E. K. The detection of atmospheric dust and temperature inversions by twilight scattering. J. Meteor. **13**, 262-8 (1956)
374. Blifford, I. H., *et al.* Geographical and time distribution of radioactivity in the air. J. Atm. and Terrestrial Phys. **9**, 1-17 (1956)
375. Blifford, I. H., Jr. H. Friedman, L. B. Lockhart, Jr., and R. A. Baus. Radioactivity of the air. NRL-4760 (February 21, 1955) (Supersedes NRL-4509)
- 376.\* Blifford, I. H., Jr. and L. B. Lockhart, Jr. Radioactivity of air and fallout samples collected on the 80th meridian. U.S. Naval Research Laboratory, NRL Memo. Rept. 626, 3p (August 1956)
- 377.\* Blifford, I. H., Jr., L. B. Lockhart, Jr., and R. A. Baus. Relationship between air concentration of radioactive fission products and fallout. Nature **177**(4517), 990-2 (May 26, 1956)
378. Blifford, I. H., L. B. Lockhart, Jr., and H. B. Rosenstock. On the natural radioactivity in the air. J. Geophys. Res. **57**(4), 499-509 (1952)
379. Blifford, I. H., Jr., L. B. Lockhart, Jr. and R. A. Baus. Collection of atomic bomb debris from the atmosphere by impaction on screens. Science **123**, 1120-1 (1956)
- 380.\* Blifford, I. H., Jr., R. L. Patterson, Fr., L. B. Lockhart, Jr., and R. A. Baus. On radioactive hailstones. Bull. Am. Meteor. Soc. **38**(3), 139-41 (1957)
381. Blifford, I. H., Jr. and H. B. Rosenstock. Fallout dosages at Washington, D. C. U.S. AEC Report, Proj. NR-612-130, October 6, 1955. NRL-4654 (TID-3061)
382. Blifford, I. H., Jr. and H. B. Rosenstock. Fallout dosages at Washington, D. C. Science **123**(3198), 619-22 (1956)

383. Bosanquet, C. H., W. F. Carey and E. M. Halton. Dust deposition from chimney stacks. *Inst. of Mech. Engineers. Proc.* **162**(3), 355-65 (1950)
384. Bowen, V. T. and T. T. Sugihara. Strontium-90 in North Atlantic surface water. *Proc. Nat. Acad. Sci. U.S.* **43**, 576-80 (1957)
- 385.\* Bradshaw, R. I. and W. D. Cottrell. Atomic weapons test fallout at ORNL on March 19, 1953. Oak Ridge National Laboratory Document ARC-101 (July 21, 1953)
- 386.\* Brier, Glenn W. The statistical theory of turbulence and the problem of diffusion in the atmosphere. *J. Meteor.* **7**(4), 283-90 (1950)
- 387.\* Brier, Glenn W. The statistical theory of diffusion by turbulent eddies. *Metero. Monographs* **1**(4), 15-9 (1951)
388. British Atomic Scientists Association. Radiostrontium fallout from continuing nuclear tests. *Science* **124**, 894 (1956)
- 389.\* Brookhaven National Laboratory. Quarterly progress report BNL-430, 64 p (October 1 - December 31, 1956)
- 390.\* Brown, I. C. and L. T. Alexander. Petrographic studies of fallout material from the surface and underground shots. Proj. 2.8 Supplementary report - Operation Jangle. WT-423
391. Bryant, R. J., A. C. Chamberlain, A. Morgan and G. S. Spicer. Radiostrontium fall-out in biological materials in Britain. (British) AERE HP/R 2056, 44 p (1956)
392. Campbell, C. I. Radiostrontium fallout from continuing nuclear tests. *Science* **124**(3227), 894 (1956)
- 393.\* Chapman, N. G. and R. W. Humphrey. An investigation of the variation of the atmospheric radioactivity at Wellington from 5 May to 18 July 1955. *New Zealand J. Sci. Tech.* **B.37**(3), 396-406 (1955)
- 394.\* Chatterjee, S. Radioactive ashes over Calcutta and a method for dating a nuclear explosion. *Atom. Scientists J. (London)* **4**(5), 273-8 (1955)
- 395.\* Chatterjee, S., A. P. Patro, B. Basu, R. L. Bhattacharyya and F. Hosain. Presence of radioactive dusts over Calcutta. *Science & Culture (Calcutta)* **19**(11), 570-1 (1954). *Ibid* **20**(8), 399-401 (1955)
396. Cherubin, L. J., *et al.* Evaluation of the effects of atomic bomb detonations in the state of Nevada on air-borne contamination at Knolls Atomic Power Laboratory, Knolls site and environs. U.S. AEC Rept. No. KAPL-559 (May 7, 1951)
397. Cherubin, L. J. and J. J. Fitzgerald. Radiological development activities in health physics. KAPL-1615 (June 1956)
398. Cholak, J., L. J. Schafer and R. F. Hoffer. Collection and analysis of solids in urban atmospheres. *Arch. Ind. Hyg. & Occ. Med.* **2**(4), 443-53 (1950)

399. Clark, H. M. The occurrence of an unusually high-level radioactive rainout in the area of Troy, N. Y. *Science* **119**(3097), 619-22 (1954)
- 400.\* Cocconi, G. Extensive air showers and the cascade theory. *Phys. Rev.* 964-6 (November 1947)
401. Cockcroft, J. Radioactive pollution from nuclear explosions. *Smokeless Air* **25**, 192-6 (Summer 1955)
- 402.\* D. Colson. Air flow over a mountain barrier. *Trans. Amer. Geo. Union* **30**(6), 818-30 (1949)
403. Coven, A. W. Evidence of increased radioactivity of the atmosphere after the atomic bomb test in New Mexico. *Phys. Rev.* **68**, 279 (1945)
- 404.\* Cramer, H. E., G. C. Gill and F. A. Record. Research on atmospheric turbulence and associated diffusion of aerosols and gases near the earth's surface. AD-37048. M.I.T. Final Rept. [Contract AF 19(604)145] 15 June 1954
- 405.\* Crosthwait, L. B. A measurement of atmospheric radioactivity at Wellington. *New Zealand J. Sci. Technol.* **B37**(3), 382-4 (1955)
406. Crozier, W. D. and B. K. Seely. Airborne particles collected on a transcontinental airplane flight. New Mexico School of Mines, Research and Development Div.: Tech. Report No. 1-NR (Contr. N7-ONR-405) (January 1949)
- 407.\* Cserady, G. T. Dispersal of dust particles from elevated sources. *Austral. J. Phys.* **8**, (4), 545-50 (1955)
- 408.\* Dalla, V., J. M. Orr and H. G. Blocker. Effect of thermal turbulence on settling of aerosols. 12th Int. Cong. Chem. 1951, abstract of Paper 17. *At. Poll. Bull. (G.B.)* **20**(6), 33 (1952)
- 409.\* Damon, P. E. and P. K. Kuroda. On the artificial radioactivity of rainfall. *Nucleonics* **11**(12), 59 (1953)
- 410.\* Damon, P. E. and P. K. Kuroda. On the natural radioactivity of rainfall. *Trans. Am. Geophysical Union* **35**(2), 208-16 (1954)
411. Daniel, J. H. and F. S. Brackett. Investigation of small, airborne, charged particles by an electrical method. *Arch. Ind. Hyg. Occ. Med.* **3**, 505-19 (1951)
412. Davis, F. J. Fallout in Southeastern U.S. during January and February 1951, from the Nevada atomic tests. TID-3061. Oak Ridge National Laboratory, ORNL-1081, November 7, 1951
- 413.\* Dawson, K. B. Radioactive material in the atmosphere. *Brit. J. Cancer* **6**, 22-31 (1952)
- 414.\* Devaux, P. Aerial studies of atomic dangers. *Science et vie* **78**, 395-8 (1950)
- 415.\* Diem, M. Effect of meteorological conditions on dust dispersion in the free atmosphere. *Staub* **15**, 342-55 (September 1951); *Atm. Poll. Bull.* **20**(3), 58 (1952)

416. Dietze, G. Size distribution of atmospheric aerosol and skylight polarization. *Z. Meteor.* **10**(12), 354-63 (1956)
417. Donaldson, L. R., A. H. Seymour, E. E. Held, N. O. Hines, F. G. Lowman, P. Olson and A. D. Welander. Survey of radioactivity in the sea near Bikini and Eniwetok Atolls, June 11-21, 1956. U.S. AEC UWFL-46, 39 p (1956)
- 418.\* Dunning, G. M. Radioactive contamination of certain areas in the Pacific Ocean from nuclear tests. U.S. AEC (1957)
- 419.\* Edinger, J. G. On the dispersal of large particles in the atmosphere. *Bull. Am. Meteor. Soc.* **36**(5), 211-5 (1955)
- 420.\* Eisenbud, M. Measuring fallout radiation. Statement before the Joint Committee on Atomic Energy, 5 p. NYO-4753 (April 15, 1955)
421. Eisenbud, M. The AEC fallout monitoring network. *J. Air Poll. Control. Assoc.* **6**, 144-6 (1956)
- 422.\* Eisenbud, M. Monitoring network for measuring radioactive fallout. *J. Am. Water Wks. Assoc.* **48**, 659-64 (1956)
- 423.\* Eisenbud, M. AEC fallout monitoring network. *Am. Inst. of Chem. Eng.*, New York 36, N.Y. Preprint 192, 14 p. NYO-4753
424. Eisenbud, M. Global distribution of radioactivity from nuclear explosions with special reference to strontium. *J. Wash. Acad. Sci.* **47**, 180-8 (1957)
425. Eisenbud, M. Global distribution of strontium-90 from nuclear detonations. *Sci. Monthly* **84**, 237-44 (1957)
426. Eisenbud, M., B. Hanson and E. V. Barry. How important is surface contamination? *Nucleonics* **12**, 12-15 (August 1954)
- 427.\* Eisenbud, M. and J. H. Harley. Radioactive dust from nuclear detonations. *Science* **117**, 141-7 (1953)
428. Eisenbud, M. and J. H. Harley. Radioactive fallout in the United States. *Science* **121**, 677-80 (1955)
- 429.\* Eisenbud, M. and J. H. Harley. Radioactive fallout through September 1955. *Science* **124**(3215), 251-5 (1956)
- 430.\* Ekhardt, E. The yearly course of overcast in world-wide presentation. AEC-tr-3091. [Trans. from *Meteor. Abhandl.* **2**, 39-52 (1955)]
431. Eliassen, R. and R. A. Lauderdale. Radioactive fallout in water supply at Portland, Maine. *J. Am. Water Works Assoc.* **48**, 665-70 (1956)
432. Faferman, A. and M. H. Shamos. Effect of fall-out from atomic blast on background counting rate. *Nucleonics* **11**(6), 80-1 (1953)
- 433.\* Farma, P. Study of airborne activity resulting from decontamination of ships contaminated with radioactive fallout. US NRDL-TR-94 (May 22, 1956)

- 434.\* Farrigue, H. Radioactivity of the atmosphere. *Compt. Rend.* **241**, 1971-2 (1955)
435. Fearson, R. E., A. W. Engle, J. Thayer, *et al.* Results of atmosphere analyses done at Tulsa, Oklahoma, during the period neighboring the time of the second Bikini atomic bomb test. *Phys. Rev.* **70**(7/8), 564 (1956)
- 436.\* Fedorov, E. K. The influence of atomic explosions on meteorological processes. *J. Nuclear Energy* **5**, 135-45 (1957)
437. Fedorow, J. K. The influence of atomic explosions on the meteorological processes. *Atomkernenergie* **2**, 266-72 (1957)
- 438.\* Fedorov, E. K. and V. I. Baranov. Content of natural radioactive substances in the atmosphere and in natural waters in the territory of the U.S.S.R. AEC-tr-3054 (Transl. from a publication of Acad. Sci., USSR, Moscow, 1956, 24 p)
- 439.\* Fitzgerald, J. J. Determination of radioactive fallout. U.S. AEC Rept. KAPL 1439 (February 9, 1956)
- 440.\* Fitzgerald, J. J. A rapid and sensitive method of monitoring beryllium aerosols. *Arch. Ind. Health* **15**, 68-73 (1957)
- 441.\* Fitzgerald, J. J. and D. G. Chappell. Graphic aids to estimate nuclear radiation hazards. KAPL-1178 (August 30, 1954)
- 442.\* Fitzgerald, J. J., H. Hurwitz, Jr. and L. Tonks. Methods for evaluating radiation hazards from a nuclear incident. U.S. AEC Rept. No. KAPL-1045 (March 26, 1954)
- 443.\* Fleagle, R. G. and F. I. Badgley. Atmospheric turbulence study; annual progress report, 1 August 1949 - 30 April 1951. AECU-2023; Occasional Report No. 1 (April 1951)
- 444.\* Fletcher, R. D. and N. E. Manos. The importance of several meteorological elements in the spreading of smoke. *Bull. Am. Meteor. Soc.* **31**, 365-70 (1950)
445. Frenkiel, F. N. and I. Katz. Studies of small-scale diffusion in the atmosphere. *J. Meteor.* **13**, 388-94 (1956)
- 446.\* Fuquay, J. J. Meteorology as related to waste disposal and weapons tests. HW-47721A (January 15, 1957). Supersedes HW-47721
- 447.\* Gabites, J. F. Drift of radioactive dust from the British nuclear bomb tests in October 1953. New Zealand Meteorological Office Note No. 40 (1954); also in *N.Z. J. of Sci. & Tech.*, Sec. B, **36**(2), 160-5 (1954)
448. Gamertsfelder, C. C. and R. L. Waterfield. Method of estimating dosage to ground from a radioactive cloud. U.S. AEC Rept. No. APEX-348 (October 1955)
- 449.\* Garrigue, H. On the natural radioactivity of the atmosphere. *Compt. Rend.* **230**, 1272-4 (1950)

- 450.\* Garrigue, H. Renewal of anomalies in atmospheric radioactivity at middle altitude. Acad. Sciences (Paris), Compt. Rend. **232**(9), 827-9 (1951)
- 451.\* Garrigue, H. The invasion of radioactive air of atomic origin and its effect on precipitation. Compt. Rend., **232**(10), 1003-4 (1951)
- 452.\* Garrigue, H. Research on the radioactivity of free air. Compt. Rend. **233**(16), 860-2 (1951)
- 453.\* Garrigue, H. Researches in radioactivity at the top of Puy-de-Dôme. Compt. Rend. **233**(23), 1447-8 (1951)
- 454.\* Garrigue, H. Researches on atmospheric precipitation on a global scale. Compt. Rend. **234**, 1571-3 (1952)
- 455. Garrigue, H. On abnormal radioactivity of the atmosphere. Compt. Rend. **235**(23), 1498-9 (1952)
- 456.\* Garrigue, H. Observations on the impurities in free air. Compt. Rend. **236**, 2309-11 (1953)
- 457. Garrigue, H. Determination of the radioactivity of the air. Compt. Rend. **237**, 802-3 (1953)
- 458.\* Garrigue, H. Radioactivity of the atmosphere of atomic origin. Compt. Rend. **237**, 1232-3 (1953)
- 459.\* Garrigue, H. Research on atmospheric radioactivity. Compt. Rend. **238**, 2074-5 (1954)
- 460.\* Garrigue, H. Radioactivity of the atmosphere of atomic origin. Compt. Rend. **240**, 178-80 (1955)
- 461.\* Garrigue, H. Another renewal of atmospheric radioactivity of atomic origin. Compt. Rend. **240**(13), 1453-5 (1955)
- 462.\* Garrigue, H. Radioactivity of the air and precipitations. Compt. Rend. **243**, 584-5 (1956)
- 463.\* Gates, D. M. Some research in the atmospheric physics. University of Paris. ONRL-44-57
- 464.\* Gerlach, W. Investigations of radioactive rain. AEC-tr-2893 [Translated from Atomkernenergie, 1, 237-44 (1956)]
- 465.\* Gifford, F., Jr. Relative atmospheric diffusion of smoke puffs. J. Meteor. **14**, 410-4 (1957)
- 466.\* Gilbert, G. H. Fall-out from large nuclear explosions with applications to civil defence. Canada Defence Research Board, ORG Memo., No. 55/6, 18 p (March 6, 1955)

- 467.\* Goodale, T. C., B. M. Carder and E. C. Evans. Dust particles in high Velocity air streams; representative sampling. Am. Ind. Hyg. Assoc. Q. **13**, 226-31 (1952)
468. Gosline, C. A. Dispersion from short stacks. Chem. Eng. Prog. (Engineering Sec.) **48**, 165-72 (April 1952)
- 469.\* Grant, C. K. Airborne radioactivity surveys. Australia Dept. Mines, Mining Rev. 1952, No. 97, 117-30 (1954)
470. Greenfield, S. M., *et al.* A catalog of fallout patterns. Rand Corp., Research Memo. RM-1676-AEC, for USAEC Contract No. AT(11-1)-135, 93 p, (April 1956)
- 471.\* Grodzovskii, G. L. Automodel motion of gas in a strong peripheral explosion. AEC-tr-2916. (Transl. from Dokl. Akad. Nauk SSSR **111**), 969-71 (1956)
- 472.\* Gunn, R., and B. B. Phillips. An experimental investigation of the effect of air pollution on the initiation of rain. J. Meteor. **14**, 272-80 (1957)
- 473.\* Gutenberg, B. New data on the lower stratosphere. Bull Am. Meteor. Soc. **30**, 62-4 (1949)
474. Harley, J. H., ed. Operation Troll. Preliminary Report. NYO-4656, 41 p (March 1956)
475. Harley, J. H. Operation Troll. U.S. AEC NYO-4656, 37 p (1956)
476. Harrassowitz, H. Atomic bomb explosions and the pll of rain. Naturwissenschaften **43**, 11-2 (1956)
477. Harris, D. L. Effects of radioactive debris from nuclear explosions on the electrical conductivity of the lower atmosphere. J. Geophys. Res. **60**(1), 45-52 (1955)
- 478.\* Harris, W. B. Spread of particulate contamination from stacks. Arch. Ind. Health **15**, 274-83 (1957)
- 479.\* Hatch, L. I., J. J. Martin and W. S. Ginell. Ultimate disposal of radioactive wastes. BNL-1781 (February 1954)
- 480.\* Harrison, H. T. Some meteorological problems indicated for jet transport operation at 40,000 feet. Aeronautical Engineering Rev. (April 1951)
481. Haxel, O. and G. Schumann. On the radioactive contamination of the atmosphere. Naturwissenschaften **40**(17), 458-9 (1953)
- 482.\* Haxel, O. and G. Schumann. Self-purification of the atmosphere. Z. Phys. **142**(2), 127-32 (1955)

483. Hay, J. S. and F. Pasquill. Measurement of the short range diffusion of airborne particles at a height of a few hundred feet in the atmosphere. AD-115-205. Portion Tech. rept. 561
484. Heidt, W. B., Jr., E. A. Schuert, W. W. Perkins and R. L. Stetson. Nature, intensity and distribution of fallout from Mike Shot, Operation Ivy. Proj. 5.4a, US NRDL. WT-615 (November 1952)
485. Heininger, C. and J. Turkevich. The nature of atmospheric dust. Radioactive and electron microscope measurements on fall-out on Princeton, N.J., Oct. 21, 1954 to Aug. 10, 1955. Progress Report to August 31, 1955. NYO-3434, 24 p (December 1, 1955)
- 486.\* Herbst, W., R. Neuwirth and K. Philipp. Considerations of the suitability of radioactive atomic aerosols as an indicator in meteorological flow investigations. *Naturwissenschaften* **41**, 156-60 (1954)
- 487.\* Herbst, W. and K. Philipp. The path of an atomic explosion aerosol. *Naturwissenschaften* **40**, 54 (1953)
- 488.\* Herbst, W. and K. Sommermeyer. Gamma spectra of the radioactive fallout from the atmosphere. *Naturwissenschaften* **44**, 392 (1957)
- 489.\* Herzog, G. Gamma-ray anomaly following the atomic bomb tests of July 1, 1946. *Phys. Rev.* **70**(3/4), 227-8 (1946)
- 490.\* Heslep, J. M. and A. W. Bellamy. Sampling for airborne radioactivity. *Air Repair* **5**, 1-4 (1955)
- 491.\* Hewson, E. W. Research on turbulence and diffusion of particulate matter in the lower layers of the atmosphere. Progress Report No. 6, February 1 April 30, 1950. NP-3501 (May 10, 1950)
- 492.\* Hewson, E. W. Meteorological influences and their application to control at the source. *Boston Am. Meteor. Soc., Meteor. Monographs* **1**(4) (November 1951)
- 493.\* Hewson, E. W. Meteorological factors affecting causes and control of air pollution. *J. A.P.C.A.* **5**(4), 235-41 (1956)
494. Hicks, E. P. and W. G. Penney. Symposium on the physical effects of atomic weapons. Paper No. 14. The base surge: the mechanism of fallout. FWE-19 (September 24, 1954)
495. Hilst, G. R. Some observations of particle distribution with height in the lower atmosphere. 4th AEC Air Cleaning Conference, ANL, November 1955. TID 7513 (Part 1), 155-76 (June 1956)
- 496.\* Holter, N. J. and W. R. Glasscock. Tracing nuclear explosions. *Nucleonics* **10**(8), 10-13 (1952)
- 497.\* Horie, K. Damping of radioactivity of the Bikini ashes. *Kagaku (Science)* **25**, 636-7 (1955)



- 498.\* Hummel, R. W. and A. A. Smales. Determination of strontium in sea water by using both radioactive and stable isotopes. *Analyst* **81**, 110-13 (1956)
- 499.\* Isibashi, M., T. *et al.* Radiochemical analysis of the Bikini ashes. Kyoto Univ: Inst. for Chem. Res., Bulletin (Supplementary issue), 39-59 (November 1954)
- 500.\* Jacobs, Paul. Clouds from Nevada; a special report on the AEC's weapons-testing program. *The Reporter* **16**, 10-29 (1957).
- 501.\* Jaffe, G., W. Wittman and C. C. Bates. Radioactive hailstones in the District of Columbia area, May 26, 1953. *Bull. Am. Meteor. Soc.* **35**(6), 245-9 (1954)
- 502.\* Japan Meteorological Agency. Bulletin of the Atmospheric Radioactivity, Numbers 1-8 for April 1955 through March 1957. The Japan Meteorological Agency, 570 p (1955-57)
- 503.\* Jech, C. Identification of radioactive substances in the air with crystal emulsion. *Collect. Trav. Chim. Tchecoslov.* **15**, 719-22 (1950)
- 504.\* Jech, C. Radioactive aerosols. *Pracovni Lekarstvi* **5**, 147-52 (1953)
- 505.\* Jech, C. Radioactive aerosols. *Chem. Listy* **49**, 577-614 (1955)
- 506.\* Johnson, J. R. Radioactive tracer methods. *Am. Cer. Soc. Bull.* **29**(1), 16-9 (1950)
- 507.\* Johnston, R. W. Utilization of telemetering techniques in evaluating residual radioactive contamination. Project 30.2, Operation Teapot. WT-1182, 24 p, (November 1956)
508. Junge, C. E. Das atmosphärische aerosol. *Umschau* **51**(21), 647-9 (1951)
509. Junge, C. E. The chemical composition of atmospheric aerosols. I. Measurement at Round Hill Field Station, June-July, 1953. *J. of Meteor.* **11**(4), 323-33 (1954)
510. Junge, C. E. The size distribution and aging of natural aerosols as determined from electrical and optical data on the atmosphere. *J. Meteor.* **12**, 13-25 (1955)
511. Junge, C. E. Recent investigations in air chemistry. *Tellus* **8**(2), 127-39 (1956)
- 512.\* Kahn, B., E. R. Eastwood and W. J. Lacy. Use of ion-exchange resins to concentrate radionuclides for subsequent analysis. U.S. AEC ORNL-2321, 17 p, (1957)
- 513.\* Kawabata, T. Radiologic contamination of fish. I. Distribution and migration of contaminated fish on basis of the compiled data of radiological surveys. *Japan J. Med. Sci. and Biol.* **8**, 337-46 (1955)

- 514.\* Kellogg, W. W. Diffusion of smoke in the stratosphere. *J. Meteor.* **13**, 241-50 (1956)
- 515.\* Kellogg, W. W., R. R. Rapp and S. M. Greenfield. Close-in fallout. *J. Meteor.* **14**, 1-8 (February 1957)
516. Kikichu, T., *et al.* Studies on the properties and size of the radioactive ashes from the No. 5 Fukuryu Maru. Kyoto Univ. Inst. for Chem. Res., Bulletin (suppl. issue), 4-11 (November 1954)
517. Kikichu, T., *et al.* Radioautographic studies of the radioactive ashes obtained from the no. 5 Fukuryu Maru. Kyoto Univ. Inst. for Chem. Res., Bulletin (suppl. issue), 12-17 (November 1954)
- 518.\* Kilcawley, E. J., H. M. Clark, H. L. Ehrlich, W. J. Kelleher, H. E. Schultze and N. L. Krascella. The fate of fission products deposited in the reservoirs of the Troy, N.Y., area following nuclear detonations during the spring tests of 1953. NYO-4569 (December 15, 1953)
- 519.\* Kilcawley, E. J., *et al.* Measurement of radioactive fallout in reservoirs. *J. Am. Water Works Assoc.* **46**(11), 1101-11 (1954)
- 520.\* Kimura, K., E. Minami, M. Honda, Y. Yokoyama, N. Ikeda, K. Fuwa, H. Natsume, T. Ishimori, Y. Sasaki, H. Sakai, K. Mizumachi, M. Asada, S. Abe, H. Mabuchi, Y. Suzuki, K. Komatsu, K. Nakada and K. Saruhashi. Radiochemical analysis of radioactive dusts. Proc. Internat. Conf. Peaceful Use Atomic Energy, Geneva, 1955, 7, 196-209 (1956)
- 521.\* Kimura, K., E. Minami, N. Saito, Y. Sasaki and N. Kokubu. Radiochemical interpretation of the radioactive fallout. Proc. Internat. Conf. Peaceful Uses of Atomic Energy, Geneva, 1955, 7, 210-3 (1956)
- 522.\* King, P., L. B. Lockhart, Jr., R. A. Baus *et al.* RaD, RaE, and Po in the atmosphere. *Nucleonics* **14**(6), 78, 80-4 (1956)
- 523.\* Kosaka, T., H. Watanabe, I. Tadaichi, I. Tatsuji and S. Nozaki. Radioactive rain and contaminated atmosphere observed in Niigata City (Japan). First report: The effect of environment and human body. *Niigata Med. Assoc. J.* **69**, 1-6 (1955)
- 524.\* Krasnogorskaia, N. V. Photoelectrical method of investigating the distribution of particle size in precipitation. *Akad. Nauk SSSR, Izv., Ser. Geofiz.* **6**, 529-37 (November/December 1955)
525. Kruglak, H. Radioactive fallout counts at Kalamazoo, Michigan. Presented at spring meeting of Michigan Teachers of College Physics, May 7, 1955
- 526.\* Kulp, J. L., B. J. Gilletti and W. S. Broecker. Radioactive isotopes in the atmosphere. Columbia Univ. Lamont Geol. Obs. Contract AF 19(604) 851. Final Report (July 15, 1956)

527. Kurchatov, V. V. Study of the atmospheric content of strontium-90 and other long-lived fission products. AEC-tr-3056 [Transl. from a publication of the Acad. Sci. USSR, Moscow (1956)]
528. Kyoto Univ. (Inst. for Chem. Res.). Radioactive dust from the nuclear detonation. Bulletin, Supplementary Issue (November 1954)
- 529.\* Labeyrie, J. Aerosols and radioactive gases in the atomic industry. L'Onde Electrique, **35**, 929-37 (1955)
530. Lapp, R. E. Radioactive fallout. III. Bull. Atom. Scientists **11**, 206-9 (1955)
531. Lapp, R. E. Global fallout. IV. Bull. Atom. Scientists **11**, 339-43 (1955)
- 532.\* LaRiviese, P. D. The relationship of time of peak activity from fallout to time of arrival. NRDL Rept. No. TR 137
- 533.\* Letteau, H. Effect of turbulence on the gaseous composition of the stratosphere. Amer. Meteor. Soc. Preprint (January 1948)
- 534.\* LeVine, H. D. and R. T. Graveson. Measurement of off-site fallout by automatic monitoring stations. Proj. 30.1 - Operation Teapot. WT-1187 (December 1956)
- 535.\* Ley, W. The upper atmosphere - its exploration and exploitation. Aeronautical Eng. Rev. (February 1951)
536. Libby, W. F. Fallout from the A-bomb. Ordnance **41**, 40-3 July/August (1956)
- 537.\* Libby, W. F. Radioactive fallout. Remarks delivered at the annual meeting of the National Association of State Civil Defense Directors, Sheraton Park Hotel, Washington, D.C., 8 p (November 3, 1955)
- 538.\* Libby, W. F. Radioactive fallout. Remarks delivered before the Alumni Reunion the University of Chicago, Chicago, Ill. 15 p (June 3, 1956)
- 539.\* Libby, W. F. Radioactive fallout. Remarks delivered before the spring meeting of the American Physical Society, Washington, D. C., (April 26, 1957)
540. List, R. J. Annotated bibliography on the transport and deposition of atomic debris. U.S. AEC Rept. (January 20, 1956)
- 541.\* List, R. J. On the transport of atomic debris in the atmosphere. Bull. Am. Meteor. Soc. **35**(7), 315-25 (1954)
- 542.\* List, R. J. Radioactive fallout in North America from Operation Teapot. U.S. AEC Rept. NYO-4696 (February 1956)
- 543.\* Liu, V. Turbulent dispersion of dynamic particles. J. Meteor. **13**, 399-405 (1956)

544. Loveridge, B. A. and A. M. Thomas. The determination of radio-strontium in effluent. AERE C/R 2294, Gr. Brit.
- 545.\* Lynch, D. E. Radioactive debris in North America from Operation Teapot. NYO-4659 (August 1955)
546. Machta, L., H. L. Hamilton, Jr., O. F. Hubert, R. J. List and K. M. Nagler. Airborne measurements of atomic debris. J. Meteor. **14**(2), 165-75 (1957)
547. Machta, L. and D. L. Harris. Effects of atomic explosions on weather. Science **121**, 75-81 (1955)
548. Machta, L., R. J. List and L. F. Hubert. World-wide travel of atomic debris. Science **124**(3220), 474-7 (1956)
- 549.\* MacIntire, W. H. and A. J. Sterges. Role of solvated silica in promoting migrations of fluorine, phosphorus and calcium in 10-year rainwater drainage from slagged and Wollastenitised soils. Soil Science **74**, 233-47 (1952)
550. Marciano, J. J. A theoretical study of atmospheric diffusion with applications to fallout from atomic clouds. U.S. Navy Electronic Laboratory, San Diego, California. Res. Rept. 663 (February 17, 1956)
- 551.\* McCully, C. R. and G. Langer. A laboratory study on the washout of suspended dust particles by falling water drops. AD-53 465 and AD-53 466. Armour Research Foundation Scientific Reports Nos. 14 and 15
552. Meinke, W. W. Observations on radioactive snows at Ann Arbor, Michigan. Science **113**(2941), 545-6 (1951)
- 553.\* Mermagen, H. Activities of samples of precipitation following Nevada tests, p 90-5 of Quarterly Technical Report, January 1, 1951 through March 31, 1951. UR-1 64, p 90-5 (May 9, 1951)
- 554.\* Mesler, R. B. and L. C. Widdoes. Evaluating reactor hazards from airborne fission products. Nucleonics **12**(9), 39-41 (1954)
555. Miyake, Y. The artificial radioactivity in rainwater observed in Japan from May to August, 1954. Papers Meteor. & Geophys. (Tokyo) **5**(2), 173-7 (September 1954)
556. Miyake, Y. Radioactivity in rainwater and the air observed in Japan 1954-5. Geneva Conf. Proc. **13**, 345-349 (1956)
557. Miyake, Y. Artificial radioactivity in rainwater observed in Japan from autumn 1954 to spring 1955. Papers Meteor. & Geophys. (Japan) **6**, 26-32 (1955)
558. Miyake, Y. On the distribution of radioactivity in the North Pacific Ocean in 1954-5. Geneva Conf. Proc. **13**, 381-4 (1956)

559. Miyake, Y., Y. Sugiura and K. Kaneda. Distribution of the radioactivity in the sea around Bikini Atoll in June 1954. Records Oceanograph. Works Japan, **2**(1), 33-44 (1955); also Papers Meteor. & Geophys. (Japan) **5**, 253-63 (1955)
560. Miyake, Y., Y. Sugiura and K. Kameda. Artificial radioactivity in the sea near Japan. Papers Meteor. & Geophys. (Japan) **6**, 90-2 (1955)
561. Miyake, Y., K. Saruhashi and K. Kogoshi. Radiochemical analysis of fission products contained in the soil collected at Tokyo, May 1954. Papers Meteor. & Geophys. (Japan) **6**, 93-4 (1955)
562. Miyake, Y. and Y. Sugiura. Radiochemical analysis of radionuclides in sea water collected near Bikini Atoll. Papers Meteor. & Geophys. (Japan) **6**, 33-7 (1955)
- 563.\* Moraschinelli, E. Autoradiography of atmospheric aerosols. Il Nuovo Cimento **10**(9), 1341-2 (1953)
- 564.\* Moraschinelli, E. Radioactivity of atmospheric aerosols. Rend. 1st Lombardo Sci. Classe Sci. Mat. e Nat. **86**, 53-65 (1954)
- 565.\* Morton, R. J. Radioactive waste disposal research. Sec. I-60, Health Physics Division semi-annual report for period ending January 31, 1954. ORNL-1684
- 566.\* Moser, H. The details of surface discontinuities associated with thunderstorms. J. Meteor, 161-4 (August 1948)
- 567.\* Nader, J. S. Radioactive fallout in rain in the Cincinnati area. U.S. AEC WASH-275, 121-36 (1954)
568. Nader, J. S., A. S. Goldin and L. R. Setter. Radioactive fallout in Cincinnati area. J. Am. Water Works Assoc. **46**(11), 1096-1100 (1954)
- 569.\* Nahmias, M. E. Detection at a distance of atomic bomb tests. Mem. Artillerie Franc. **28**, 393-402 (1954)
- 570.\* Natanson, G. L. Radioactive aerosols. Uspekhi Khim. **25**, 1429-45 (1956)
- 571.\* National Academy of Sciences. Report of the Committee on Meteorological Aspects of the Effects of Atomic Radiation; p 45-70 of The Biological Effects of Atomic Radiation: Summary Reports. NP-6017, p 45-70 (1956)
- 572.\* Neuwirth, R. Meteorological evaluation of measurements of artificial radioactivity in the air and rainfall. Geofisica Pura Applicata **32**, 147-58 (September/December 1955)
- 573.\* Nishiwaki, Y. Bikini ash. Atom. Scientists J. (London) **4**(2), 97-109 (1954)
574. Norinder, H. and R. Siksna. Height variations in the concentration of ions near the ground during quiet summer nights at Uppsala. Tellus **3**, 234-9 (1951)

- 575.\* Obo, F. Radioactive rains and fishes in the Kagoshima area. *Igaku to Seibutsugaku (Med. & Biol.)* **33**, 19-23 (1954)
576. Olafson, J. H., H. Nishita and K. H. Larson. The distribution of plutonium in the soils of central and northeastern New Mexico as a result of the atomic bomb test of July 16, 1945. University of California at Los Angeles, Atomic Energy Project. UCLA-406 (September 19, 1957)
577. Osmond, R. G., A. G. Prachett and J. B. Warricker. The determination of long-lived fallout in rainwater. *AERE C/R 2165*, Gt. Brit.
- 578.\* Otsuka, R. and K. Shimada. On the upper currents in low latitudes of the northwestern Pacific Ocean at the beginning of March, 1954. (Meteorological investigation on the explosion at Bikini Island, Part 1). *J. Meteor. Soc. Japan, Ser. 2*, **32**(7/8), 225-39 (July/August 1954)
- 579.\* Pace, F. C. Radioactive fallout from atomic weapons. *Behind the Headlines* **16**(5), 1-12 (1956)
- 580.\* Paetzold, H. Meteorology of the stratosphere. *Wetterdienst Berichte* **4**, 43-54 (1956)
- 581.\* Pasquill, F. Preliminary studies of the distribution of particles at medium range from a ground-level point source. Great Britain Chemical Defense Experimental Establishment. PTP-498 (August 12, 1955)
- 582.\* Paxton, R. R. Measuring rate of dustfall. *Rock Products* **54**(2), 114-8 (1951)
583. Percy, T. and G. W. Hill. The accelerated motion of droplets and bubbles. *Austral. J. Phys.* **9**(1), 19-30 (1956)
- 584.\* Perry, C. H. Radiologic hazards predicted for a given height burst of an atomic bomb. AECD-3210; LADC-991 (April 6, 1951)
585. Peterson, V. Fallout - new H-bomb peril? *Chem. Eng. News* **33**, 842-3 (1955)
586. Preston, R. L. and B. G. Hogg. Radioactive fallout in Kingston, Canada. *Nature* **176**(4479), 459 (1955)
587. Rabinowitch, E. H-bombs without fall-out. *Bull. Atom. Scientists* **7**(7), 234, 264 (1956)
588. Rafter, T. A. and G. J. Fergusson. Atom bomb effect. Recent increase of  $C^{14}$  content of the atmosphere and biosphere. *Science* **126**, 555-8 (1957)
589. Rainey, C. T., J. M. Heslep, C. L. Washburn and A. W. Bellamy. Study of the dispersal of radioactive aerosols over California. State of California, Office of Civil Defense. Sacramento, California.

590. Ranz, W. E. and H. F. Johnstone. Some aspects of the physical behavior of aerosol particles in the atmosphere. AECU-2093 (May 5, 1952)
591. Rapp, R. R. A mathematical model of the phenomenon of radioactive fallout. AECU-3405 (Rand Corp.), 15 p (June 15, 1956)
- 592.\* Ratner, B. Winds and fallout: a climatological appraisal. Weather Bureau, Washington, D. C., 19 p (June 1955)
593. Reed, J. W. Weather determines blast prediction for atom tests. Weatherwise 9, 202-3 (1956)
- 594.\* Reed, J. W. Estimating safety probabilities from fallout. Forecasts for Nevada test site. Sandia Corp. SC-4073, 23 p (February 1957)
- 595.\* Rigby, M. Meteorological Abstracts and Bibliography, Vol. VII, No. V. Am. Met. Soc., Boston, Mass. AD-98738. Tech. Note No. AFCRC-TN-56-676
- 596.\* Rose, D. C. and J. Katzman. Radioactive deposits at Ottawa after the atomic explosions of January and February 1951. Can. J. Phys. 30(2), 111-6 (1952)
597. Rosenfeld, A. H., E. J. Story and S. D. Warshaw. Fallout: some measurements and damage estimates. Bull. Atom. Sci. 11, 213-16 (1955)
598. Rossby, C. J. and H. C. Willett. The circulation of the upper troposphere and lower stratosphere. Science 108, 643-52 (1948)
- 599.\* Ryder, N. V. and C. N. Watson-Munro. The detection of radioactive dust from the British nuclear bombs of October 1953. N. Z. J. of Sci. and Tech., Sec. B, 36(2), 155-9 (1954)
600. St. Clair, H. W. Agglomeration of smoke, fog or dust particles by sonic waves. Ind. Eng. Chem. 41, 2434, 2438 (1949)
- 601.\* Sandor, S. and B. Denes. Observations of unusual radioactivity in precipitations which fell in Bebreceen between April 22 - December 31, 1952. Budapest Magyar Tudomanyos Akad., 13 p (1955)
- 602.\* Sanievecici, A. and E. Friedlander. Radioactivity in the region Tusnad-Bai. Acad. Rep. Populare Romane, Bul. Stiint. A. 1, 37-8 (1948)
- 603.\* Santomauro, L. and A. Cigna. First measurements on the radioactivity of atmospheric precipitations. Ann. Geofis. 6, 381-7 (1953)
- 604.\* Schellenberger, G. On the distribution of radioactive substances in a turbulent wind field. Z. Meteor. 6(8), 225-31 (1952)
605. Schuert, E. A. A fallout forecasting technique with results obtained at the Eniwetok Proving Ground. USN Rad. Def. Lab., RCD Tech. Rept. USNRDL-TR-139, 60 p (April 1957)

606. Schuert, E. A. A fallout plotting device. USNRDL-TR-127, November 30, 1956
- 607.\* Schumann, G. Synthetic radioactive substances in the atmosphere. *Z. Angew Phys.* **8**, 361-4 (1956)
- 608.\* Setter, L. R. and A. S. Goldin. Radioactive fallout studies in surface waters. 127th Nat. Mtg., Am. Chem. Soc., U.S. Public Health Service, Robert A. Taft Sanitary Eng. Center, Cincinnati, Ohio (April 5, 1955)
- 609.\* Seymour, A. H., E. E. Held, F. G. Lowman, J. R. Donaldson and D. J. South. Survey of radioactivity in the sea and in pelagic marine life west of the Marshall Islands, September 1-20, 1956. University of Washington, Applied Fisheries Laboratory. UWFL-47, 63 p (March 15, 1957)
- 610.\* Shapiro, J. Studies on the radioactive aerosol produced by radon in air. UR-461 (August 30, 1956)
- 611.\* Shimizu, S., *et al.* Survey of the radioactive contamination of the No. 5 Fukuryu Maru. Kyoto Univ. Inst. for Chem. Res., Bulletin (Suppl. issue), 1-3 (November 1954)
612. Sievert, R. M. Records of gamma radiation from the ground and beta radiation from radioactive debris in Sweden, 1950-1955. Pt. 1. *Tellus* (Stockholm) **8**(2), 117-26 (1956)
- 613.\* Siksna, R. Radioactivity induced from the atmospheric air, investigated with the photographic emulsion method. *Ark. Geofys.* **1**, Paper 6, 123-47 (1950)
614. Sittkus, A. Migration of an artificial atomic aerosol. *Naturwissenschaften* **40**, 198 (1953)
615. Sittkus, A. Observations of radioactive swathes from atomic experiments in 1953/54. *Naturwissenschaften* **42**(17), 478-82 (1955)
- 616.\* Sivetz, M. Radioactivity induced in water. *Atoms* (Chicago) **6**(5), 4-18 (1950)
- 617.\* Smirnov, N. S. Problem of the influence of an atomic explosion on the state of the atmosphere. *Akad. Nauk SSSR, Izvestia, Ser. No. 10*, 1227-31 (1956)
- 618.\* Spilhaus, A. F. Size, shape and fall speed of rain drops. *Am. Meteor. Soc. Preprint* (January 1948)
619. Stafford, G. H. Neutron induced activity following an atomic explosion. AERE-HP/M-27 (August 1951)
- 620.\* Stanley, C. W. and P. Kruger. Determination of strontium-90 activity in water by ion-exchange concentration. *Nucleonics* **14**, 114, 116-8 (1956)



621. Stead, F. W. Airborne radioactivity surveying USA. J. A.P.C.A. **6**, 147-50 (1956)
622. Stefanizzi, A. On the radioactivity of atmospheric precipitates. J. Geophys. Res. **55**, 373-8 (1950)
- 623.\* Stewart, N. G., R. N. Crooks and E. M. R. Fisher. The radiological dose to persons in the U.K. due to debris from nuclear test explosions. Great Britain, AERE HP/R 1701 (June 1955)
624. Stewart, N. G., R. N. Crooks and E. A. R. Fisher. The radiological dose to persons in the U.K. due to debris from nuclear test explosions prior to January 1956. AERE- HP/R-2017, 29 p (September 1956)
625. Storebo, P. B. and K. Edvarson. Radioactive fallout over the Scandinavian peninsula between July and December 1956. A joint report. Norway Defence Res. Establishment and Sweden Res. Inst. of Natl. Defence, Stockholm. NP-6394, 7p
- 626.\* Sugaira, Y. and T. Kanazawa. Radioactive fallout collected in Tokyo on November 26, 1955. Papers Meteor. & Geophys. (Tokyo) **7**, 128-35 (1956)
- 627.\* Suito, E., K. Takiyama and N. Uyeda. Colloid morphological and crystalline studies of "Bikini dust" fallen on the No. 5 Fukuryu Maru by electron microscopy and diffraction methods. Kyoto Univ. Inst. for Chem. Res., Bull. (Suppl. issue), 18-28 (November 1954)
- 628.\* Sutton, O. G. The stack problem of atmospheric pollution. Discovery **14**, 203-6 (July 1953)
629. Sutton, G. Thermonuclear explosions and the weather. Nature **175**, 319-21 (1955)
- 630.\* Swain, P. W. How to size up the atomic bomb. Part 2. Power **94**, 74-9 (1950)
- 631.\* Swain, P. W. How to size up the atom bomb. Part 3. Power **95**(1), 3, 82-8 (1951)
- 632.\* Szalay, A. and Berenyi. Unusual radioactivity observed in the atmospherical precipitation in Debrecin (Hungary) between April 22 - December 31, 1952. Acta. Phys. Hungar **5**(1), 1-14 (1955)
633. Tajima, E. and T. Doke. Airborne radioactivity. Science **123**, 211-4 (1956)
- 634.\* Tajima, E., and T. Doke. Radioactivity in the open air. Kagaku (Science) **26**, 124-9 (1956)
- 635.\* Tanaevsky, O. and E. Vassy. Variations of natural and artificial radioactivity of the atmosphere. Compt. Rend. **241**(1), 38-40 (1955)

- 636.\* Tanaevsky, O. and E. Vassy. Natural and artificial radioactivity of the atmosphere. *Ann. de Geophysique* (Paris) **11**(4), 486-90 (1955)
- 637.\* Tank, W. G. The use of large scale parameters in small scale diffusion studies. *Bull. Am. Meteor. Soc.* **38**, 6-12 (1957)
- 638.\* Thomas, C. D., M. K. Gaines and T. W. Ball. Relation of radon to nonactive air contamination. *Nature* **175**, 732-3 (1955)
- 639.\* Thomas, H. A., Jr., R. S. Kleinschmidt, F. L. Parker, *et al.* Radioactive fallout in Massachusetts surface waters. *J. Am. Water Works Assoc.* **45**(6), 562-8 (1953)
640. Thomas, I. E. and C. G. Bell, Jr. Fate of fission products in the Illinois river systems. U.S. AEC TID-7517, Pt. 1b, 471-3 (1956)
641. Trevithick, R. W. Quarterly Report of KAPL Environmental Monitoring Radiological Services Sub-Unit, April, May, June 1953. Knolls Atomic Power Laboratory, Schenectady, N.Y. KAPL-1008 (1953)
- 642.\* Tunitskii, N. N. Diffusion processes in the condition of natural turbulence. *J. Phys. Chem. (USSR)* **20**, 1137-41 (1946)
643. Tunnicliffe, P. R. Proportional alpha counter for atmospheric dust filters. Nat. Res. Council, Canada, Atomic Energy Project, Div. Research. NRC No. 1619, CR-Tec-329, April 8, 1947
- 644.\* U.S. Air Weather Service. Radioactivity fall-out plots. Air Weather Service Manual 105-33 (October 15, 1954)
- 645.\* U.S. Atomic Energy Commission. Survey of fallout of radioactive material following the Las Vegas, Nevada, test explosions, 1 p (February 27, 1951)
- 646.\* U.S. Atomic Energy Commission. Dust and precipitation sampling program, 1 p April through June 1951
647. U.S. Atomic Energy Commission. Major activities in the atomic energy programs, January - June 1957. Government Printing Office, Washington, D. C., 274 p (July 1957)
- 648.\* U.S. Congress, Joint Committee on Atomic Energy. Health and safety problems and weather effects associated with atomic explosions. U.S. Government Printing Office. 60 p (1955)
649. U.S. Federal Civil Defense Administration. Facts about fallout. U.S. Government Printing Office, Washington, D. C., 16 p (1955)
- 650.\* U.S. Federal Civil Defense Administration. Radioactive fallout problem. U.S. Govt. Printing Office, Washington, D. C., 3 p (1955)
651. U.S. Federal Civil Defense Administration. What you should know about radioactive fallout. U.S. Govt. Printing Office, Washington, D. C., 31 p (1955)

- 652.\* U.S. Office of Naval Research, London. Atmospheric radioactivity following nuclear explosions. Tech Report. ORNL-66-52 (July 3, 1952)
- 653.\* U.S. Weather Bureau. Fallout of radioactive debris. Circular Letter 7-55 (February 16, 1955)
- 654.\* U.S. Weather Bureau. Meteorology and atomic energy. AECU-3066 (July 1955)
- 655.\* Van Zandt, T. E. The probability distribution of fallout patterns due to wind variability. Sandia Corp., AECU-3494 (March 1, 1957)
- 656.\* Vi-Cheng Liu. Turbulent dispersion of dynamic particles. J. Meteor. **13**, 399-405 (1956)
- 657.\* Wan-cheng Chiu. The observed mean monthly wind fields in the lower stratosphere and upper troposphere over North America. N.Y.U. Scientific Report No. 1. Rept. No. ARCRC TN-37-289
- 658.\* Warners, C. P. Note on radioactive compounds in the atmosphere. Tellus **7**(3), 403-4 (1955)
- 659.\* Watanabe, M. On the artificial radioactive rain water observed at Sendai from April to August 1955. J. Meteor. Res. (Tokyo) **8**(3), 130-7 (1956)
- 660.\* Webb, W. L. Particulate counts in natural clouds and fogs. J. Meteor. **13**, 203-11 (1956)
- 661.\* Webb, J. H. The fogging of photographic film by radioactive contaminants in cardboard packaging materials. Phys. Rev. **76**, 375-80 (1949)
- 662.\* Weisbros, S., and G. E. Hudson. A study of high-altitude wind research. Part I. Methods and bibliography. AD-128 911. Smyth Research Associates, San Diego. Rept. No. SRA-30
- 663.\* Weiss, M. M. A study of the airborne radioactivity at Brookhaven National Laboratory from the Nevada tests, March through June 1953. Brookhaven Nat. Lab., Upton, N.Y. (November 1953)
- 664.\* Weiss, M. M. Summary and observations on radioactive fallout detected in the precipitation and dust during November and December 1952. Brookhaven Nat. Lab. (January 16, 1953)
- 665.\* Wexler, H., *et al.* Meteorological aspects of atomic radiation. Science **124** (3212), 105-12 (1956)
- 666.\* White, F. D. Weather Bureau and the Atomic Energy Commission. Proc. Sanitary Engineering Conf., Chicago, p 136-42, (1952)
- 667. Wilkening, M. H. Natural radioactivity as a tracer in the sorting of aerosols according to mobility. Rev. Sci. Instr. **23**, 13-6 (1952)

- 668.\* Williamson, W., Jr. Investigation and correlation of some physical parameters of fallout material. USNRDL TR-152
- 669.\* Wolman, A. Ionizing radiation materials as air pollutants. Arch. Ind. Hyg. Occ. Med. **2**, 134-6 (1950)
- 670.\* Wolman, A., *et al.* Disposal and dispersal of radioactive wastes. Science **124** (3210), 17-9 (1956)
671. Woods Hole Oceanographic Institution. Artificial stimulation of rain. Proc. of 1st Conf. on Physics of Cloud and Precipitation Particles, Pergamon Press (1957)
- 672.\* Wright, J. H., L. Taback and H. K. Skramstad. A high-speed computer for predicting radioactive fallout. J. Res. Nat. Bur. Standards **58**, 101-9 (1957)
673. Yamasaki, F. On the radioactivity found in the western suburb of Hiroshima after the explosion of an atomic bomb. J. Sci. Res. Inst. (Tokyo) **46**, 59-67 (1952)
- 674.\* Yamasaki, F. and H. Kaneko. Artificial radioactivity in rainwater. J. Sci. Res. Inst. (Tokyo) **49**, 137-43 (1955)
- 675.\* Yamasaki, F. and H. Kaneko. On the artificial radioactivity in rain water: observation of radioactivity of rain water in Tokyo from April to December 1954, and a simple method for determining the date of explosion. J. Sci. Res. Inst. (Tokyo) **49** (1391), 137-43 (1955)
- 676.\* Yamatera, H., *et al.* Radioactive dust from No. 5 Fukuryu Maru. Japan Analyst **3**, 356-61 (1954)
- 677.\* Yih, C. S. Atmospheric diffusion from a point source. NP-3525, Report No. 4, U-19167 (August 1951)

## F. EFFECTS OF FALLOUT

678. \* Anonymous. Assuring public safety in continental weapons tests U.S. AEC Document, Washington, D.C. (January 1953)
679. \* Anonymous. Atomic energy in its repercussions in life and health. from a Scientific Conf. held at National Museum of Natural History, July 1-2, 1955. Paris, L'Expansion Editeur, 254 p (1956)
680. \* Anonymous. The hazards to man of nuclear and allied radiations. Her Majesty's Stationery Office, London, 128 p (1956)
681. \* Anonymous. Radioactivity of milk (Editorial). Am. Milk R. **19**, 22 (February 1957)
682. \* Anonymous. Fallout and radiation hazards experts disagree. Chem. & Eng. News **35**, 16-9, June 24, 1957
683. \* Anonymous. Radiation safety for weapons test. Nucleonics **10**(5), 10-3 (1952)
684. \* Anonymous. Summary of report of Committee on the effects of Atomic Radiation on agriculture and food supplies. Science **124**, 63-6 (1956)
685. \* Adams, D. F. The effects of air pollution on plant life. A review. Arch. Ind. Health **14**, 229-45 (1956)
686. \* Aeberhardt, A. Nuclear explosion and internal contamination. Comm. Energie Atomique (France). Rappt. No. 587, 26 p (1956)
687. \* Alexander, G. V., R. E. Nusbaum and N. S. MacDonald. Relative retention of strontium and calcium in bone tissue. UCLA-337 June 14, 1955
688. \* Amphlett, C. B. Soil chemistry and the uptake of fission products. Research **8**, 335-40 (1955)
689. \* Amphlett, C. B. Behavior of radioactive contamination in the ground. World Crops **9**(3), 112-5 (March 1957)
690. \* Amphlett, C. B. and L. A. MacDonald. Equilibrium studies on natural ion-exchange minerals. I. Cesium and strontium. J. Inorg. and Nuclear Chem. **2**, 403-14 (1956)
691. \* Amprino, R. Relationship between the processes of reconstruction and distribution of minerals in bone. I. Investigation conducted with the method of study of absorption of roentgen rays. AEC-tr-2856 (Transl. from Z. Zellforsch v.m. Kroskop Anat. **37**, 144-83 (1952)
692. Anderson, E. C., R. L. Schuch, W. R. Fisher and W. Langham. Radioactivity of people and foods. Science **125**, 1273-8 (1957)

693. Anderson, E. C., R. L. Schuch, W. R. Fisher and M. A. Van Dilla. Barium-140 radioactivity in foods. *Science* **127**, 283-4 (February 1958)
- 694.\* Arnold, E. D. and A. T. Gresky. Relative biological hazards of radiations expected in homogeneous reactors TBR and HPR. ORNL-1982 (December 2, 1955)
695. Asling, C. W., J. G. Hamilton, D. Axelrod-Heller and B. J. Louie. The localization of certain alkaline and rare earth elements in the costochondrial junction of the rat. *Anat. Rec.* **113**, 285-300 (1952)
- 696.\* Atomic Energy of Canada, Ltd. Levels of strontium-90 in Canada up to December 1956. Atomic Energy of Canada, Ltd., CRC-689, 16 p (February 1957)
- 697.\* Atomic Weapons Research Establishment, Aldermaston, Berks, England. Agricultural and biological investigations pertaining to contamination by fission products (misc. papers). FWE-10, July 16, 1954
698. Auerbach, C. Biological hazards of nuclear and other radiations. *Nature* **178**, 453-4 (1956)
699. Bailey, J. C. and H. F. Henry. Maximum allowable concentration for air-borne beta contamination. AECD-3753 (July 5, 1951)
- 700.\* Ballou, J. E. and R. C. Thompson. The long term retention of cesium in the rat following a single intraperitoneal injection. HW-46150 (April 1, 1957)
- 701.\* Barondes, R. and D. I. Levine. Atomic radiation effects: the release and neutralization of humoral toxic agents. *Mil. Surg.* **105**(2), 153-60 (1949)
- 702.\* Beck, J. S. P. and W. A. Meissner. Radiation effects of the atomic bomb among the natives of Nagasaki, Kyushu. *Am. J. Clin. Path.* **16**, 586-92 (1946)
703. Becker, R. R., *et al.* Nutritional and biochemical effects of irradiation. *Food Technol.* **10**, 61-4 (1956)
704. Bertrand, G. and D. Bertrand. The presence and content of cesium in arable soils. *Comp. Rend.* **229**, 533-5 (1949)
705. Biddulph, O. Studies of mineral nutrition by use of tracers. *Bot. Rev.* **21**, 251-295 (1955)
- 706.\* Binks, W. Radiation injury and protection - maximum permissible exposure standards. Geneva Conf. Proc. **13**, 129-31 (1956)
- 707.\* Bledsoe, R. W., C. L. Comer and H. C. Harris. Absorption of radioactive calcium by the peanut fruit. *Science* **109**, 329-30 (1949)

708. \* Blair, H. A., ed. Biological effects of external radiation. Nat. Nuclear Energy Series Div. VI - Vol. II, McGraw-Hill, N.Y., 508 p (1954)
709. \* Bloom, W., ed. Histopathology of irradiation from external and internal sources. Nat. Nuclear Energy Series Div. IV - Plutonium Project Record, Vol. XXII - I. McGraw-Hill, N.Y., 808 p (1948)
710. \* Blume, J. M., C. E. Hagen and R. W. Mackie. Radiation injury to plants grown in nutrient solutions containing  $P^{32}$  Soil Sci. **70**, 415-26 (1950)
711. \* Bond, V. P., *et al.* Medical examination of Rongelap people 6 months after exposure to fall-out. Addendum report for Proj. 4.1A - Operation Castle. Naval Med. Res. Inst., Bethesda, and N.R.D.L., San Francisco. WT-937, 46 p (April 1955)
712. Booker, D. V. Radiocaesium in dried milk. Phys. in Med. and Biol **2**, 29-35 (July 1957)
713. \* Booker, D. V., F. J. Bryant, A. C. Chamberlain, A. Morgan and G. S. Spicer. Radiostrontium and radiocaesium measurement in biological materials to December 1956. Atom. En. Res. Estab. AERE-HP/R-2182, 11 p (1957)
714. Bowen, H. J. M. The uptake of calcium and strontium by plants from soils and nutrient solutions. J. Exp. Botany **7**, 264-72 (1956)
715. Bowen, H. J. M. and J. A. Dymond. Strontium and barium in plants and soils. Paper 4. AERE-SPAR-4 (July 1955)
716. \* Bowen, I. G., D. R. Richmond, M. B. Wetherbe and C. S. White. Biological effects of blast from bombs Glass fragments as penetrating missiles and some of the biological implications of glass fragmented by atomic explosions. AECU-3350 (Lovelace Foundation for Med. Edu. & Res.) (June 18, 1956)
717. \* Brockett, J. W., Jr. and O. R. Placak. Removal of radioisotopes from waste solutions by soils. Proc. Ind. Waste Conf., 8th Cong. **1953**, 393-409 (1954)
718. \* Brown, E. G., *et al.* Dust storms and their possible effect on Health. With special reference to the dust storms in Kansas in 1935. Pub. Health Repts. (U.S.) **50**, 1369-83 (1935)
719. Bryant, F. J., *et al.* Radiostrontium in soil, grass, milk and bone in the United Kingdom: 1956 results. AERE-HP/R-2353, 33 p (August 1957)
720. \* Butler, J. A. V. The action of ionizing radiations on biological materials: facts and theories, Radiation Research **4**, 20-32 (1956)

721. \* Caldecott, R. S., *et al.* Modification of radiation-induced injury by post-treatment with oxygen. *Nat. Acad. Sci. of USA Proc.* **43**, 975-83 (1957)
722. \* Cannon, J. L. Effecto of uranium-vanadium deposits on the vegetation of the Colorado Plateaus. *Am. J. Science* **250**, 735-70 (1952)
723. \* Carritt, D. E. and S. Goodgal. Sorption reactions and some ecological implications. *Deep-Sea Res.* **1**, 224-43 (1954)
724. \* Casida, J. E. and T. C. Allen. Absorption and translocation of insecticides by plants. *Agr. Chem.* **7**, 41-43, 135, 137 (June 1952)
725. Caster, W. O. Strontium-90 hazards. *Science* **125**, 1291-2 (1957)
726. Catsch, A. The influence of isotopic and nonisotopic carriers on the behavior of strontium-90 in the rat. *Experientia* **13**, 312-13 (1957)
727. \* Chamberlain, A. C. and R. C. Chadwick. Experiments on the uptake of iodine-131 vapor by grass. *Gr. Brit. AERE-HP/R-993* (1952)
728. Chamberlain, A. C., J. F. Loutit, R. P. Martin and R. S. Russell. The behavior of iodine-131, strontium-89 and strontium-90 in certain agricultural food chains. *Geneva Conf. Proc.* **13**, 360-3 (1956)
729. Chen, P. S., Jr. and W. F. Neuman. Renal reabsorption of calcium by its inhibition by various chemical agents. *Am. J. Physiol.* **180**, 632-6 (1955)
730. \* Chulkov, P. M., *et al.* Presence of strontium-90 in soils and vegetation in the surroundings of Moscow. *Pochvovadenie* (4), 28-34 (April 1957)
731. \* Clayton, C. G. Radioactive contamination of foodstuffs from fall-out as a source of error in some animal experiments. *Nature* **179** (4564), 829-30 (1957)
732. \* Cockcroft, J. D. Biological effect of nuclear explosions. *Pharm. J.* **174**, 387-8, 391 (1955)
733. \* Cockcroft, J. Radiological hazards from nuclear explosions and nuclear power. *Nature* **175**(4464), 873-5 (1955)
734. \* Cohn, S. H., *et al.* Air-borne simulants of fall-out from nuclear detonation preparation and biological application. *Abs. of Papers, 130th Meeting A.C.S., Atlantic City, N.J., Sept. 16-21* (1956)
735. \* Cohn, S. H., *et al.* Studies on the metabolism of inhaled aerosols of strontium and calcium. *USNRDL-TR-175*, 30 p (May 27, 1957)
736. \* Cohn, S. H. and J. K. Gong. Effect of chemical agents on skeletal content and excretion of strontium-89. *Proc. Soc. Expt. Biol. & Med.* **83**, 550-4 (1953)



737. \* Cohn, S. H., J. K. Gong and W. L. Milne. Experimental treatment of poisoning from fission products. Ability of chemical agents to alter the uptake and retention of fission products in animals exposed to radioactive fallout. Arch. Ind. Health **14**, 533-4 (1956)
738. \* Cohn, S. H., W. B. Lane, J. K. Gong, R. K. Fuller and W. L. Milne. Radiotoxicity resulting from exposure to fallout simulant. II. The metabolism of an inhaled and ingested simulant of fallout produced by a land-based nuclear detonation. USNRDL-TR-118, 29 p (January 11, 1957)
739. Cohn, S. H., W. B. Lane, J. K. Gong, J. C. Sherwin and W. L. Milne. Inhalation and retention of simulated radioactive fall-out by mice. I. Study of a simulant of fall-out from nuclear detonation under sea water Arch. Ind. Health **14**, 333-40 (1956)
740. \* Cohn, S. H., W. B. Lane, J. C. Sherwin, J. K. Gong and L. Weisbecker. The preparation and biological application of airborne simulants of fallout from nuclear detonation J. A.P.C.A. **7**, 20-5 (May 1957)
741. \* Cohn, S. H. and W. L. Milne. The effects of combined administration of strontium-90 and external radiation AD-102 588. Tech. Rept. No. 89
742. \* Cohn, W. H., R. W. Rinehart, J. S. Robertson, J. K. Gong, W. L. Milne, W. H. Chapman and V. P. Bond. Internal radioactive contamination of human beings accidentally exposed to radioactive fallout material. USNRDL-TR-86 (May 9, 1956)
743. Comar, C. L. Radioisotopes in animal physiology and nutrition - mineral metabolism. Geneva Conf. Proc. **12**, 245-51 (1956)
744. \* Comar, C. L., ed. Atomic energy and agriculture. Am. Assoc. Advan. Sci., Publ. No. 49, Washington, D.C. (1957)
745. \* Comar, C. L., B. F. Trum, U. S. G. Kuhn, R. H. Wasserman, M. M. Nold and J. C. Schooley. Thyroid radioactivity after nuclear weapons tests. Science **126**, 16-8 (1957)
746. \* Comar, C. L. and R. H. Wasserman. Progress in nuclear energy, Series VI, Biological Sciences, Vol. 1. Pergamon Press, London, 153 p (1956)
747. Comar, C. L., R. H. Wasserman, S. Ullberg and G. A. Andreas. Strontium metabolism and strontium-calcium discrimination in man. Proc Soc. Exptl. Biol. Med. **95**, 386-91 (1957)
- 747a. Comar, C. L., R. S. Russell, R. H. Wasserman. Strontium-calcium movement from soil to man. Science, **126**, 485-92 (1957)
748. \* Conard, R. A., B. Cannon, C. E. Huggins, J. B. Richards and A. Lowery. Medical survey of Marshallese two years after exposure to fallout radiation. BNL-412, 18 p (March 1956)
749. Copp, D. H., D. S. Axelrod and J. G. Hamilton. The deposition of radioactive metals in bone as a potential health hazard. Am. J. Roentgenol. Radium Therapy **58**, 10-6 (1947)

- 750.\* Copp, D. H. *et al.* The effect of age and low P rickets on calcification and the deposition of certain radioactive metals in bone. Conf. Metabolic Interrel., Trans. **3**, 226-58 (1951)
- 751.\* Cornfield, J. Retention of radon by the mouse. *Nucleonics* **5**, 68-75 (Oct. 1949)
- 752.\* Cronkite, E. P., V. P. Bond, W. H. Chapman and R. H. Lee. Biological effect of atomic-bomb gamma radiation. *Science* **122**, 148-50 (July 22, 1955)
- 753.\* Cronkite, E. P., V. P. Bond and C. L. Dunham. Some effects of ionizing radiation on human beings. (A report on the Marshallese and Americans accidentally exposed to radiation from fallout and a discussion of radiation injury in the human being.) TID-5358, 114 p (July 1956)
- 754.\* Cronkite, E. P. and W. H. Chapman. A critical analysis of the syndrome of acute total body radiation illness. *Mil. Surg.* **104**, 7-21 (1949)
755. Curtis, T. J. and R. Dix. Distribution of alpha radioactivity in native vegetation. *Bot. Gaz.* **117**, 231-8 (1956)
- 756.\* Dautrebande, L., D. Cartny, J. Van Kerkorn and A. Areghetti. Test for the prevention of silicosis. Union Minière du Haut, Katanger, Belgium. RC 774 D 26e, 177 p (1954)
- 757.\* Dautrebande, L., *et al.* Aerosols. Effect of saline aerosols on dust in atmosphere; reduction of dust deposition in lungs by saline aerosols. *Occup. Med.* **5**, 506-21 (1948)
- 758.\* den Hoed, D. Biological aspects of the atomic bomb. *Nederlander Tijdehr Geneeskunde* **90**(I), 61-4 (1946)
- 759.\* Dick, J. L., W. R. Hurdlow and E. M. Hippeli. Safe levels of contamination from fission products. Project 7801. AFSWC-TN-56-2 (April 27, 1956)
760. Dion, H. G., C. F. Bedford, R. J. St. Arnaud and J. W. T. Spinks. Plant injury from  $P^{32}$ . *Nature* **163**, 906-7 (1949)
- 761.\* Donaldson, L. R., *et al.* Radiobiological survey of Bikini, Eniwetok, and Likiep Atolls, July-August 1949. USAEC Tech. Info. Ser. Oak Ridge AECD **3446**, 8-145 (1950)
- 762.\* Dunning, G. M. Criteria for evaluating gamma radiation exposures from fallout following nuclear detonations. *Radiology* **66**, 585-94 (1956)
- 763.\* Dunning, G. M. Two ways to estimate thyroid dose from radioiodine in fallout. *Nucleonics* **14**, 38-41 (February 1946)

764. Eckelmann, W. R., J. Laurence Kulp and A. R. Schulert. Strontium-90 in man. II. *Science* **127**, 266-74 (February 1958)
- 765.\* Eden, G. E., H. G. J. Elkins and G. A. Truesdale. Removal of radioactive substances from water by biological treatment processes. *Atomic (British)* **5**, 133-42, 158 (May 1954)
766. Edington, G. M., J. M. Judd and A. H. Ward. Toxicity of radiostrontium in monkeys. *Nature* **172**, 122-3 (1953)
767. Egawa, T., *et al.* Investigations on the contamination of field crops by artificial radioactivities as the result of the H-bomb tests at Bikini Atoll. *Soil & Plant Food* **1**(1), 19-20 (1955)
768. Ehrenberg, L. and I. Granhall. Effects of beta-radiating isotopes in fruit trees. *Hereditas* **38**, 385-419 (1952)
- 769.\* Ehler, W. L., E. M. Romney and K. C. Hamner. The effect of certain environmental factors on calcium, phosphorus and strontium uptake by barley. *UCLA-351* (October 24, 1955)
770. Eisenbud, M. Retention, distribution, and elimination of inhaled particulates, with particular reference to the evaluation of radiologic risk. *Arch. Ind. Hyg. & Occ. Med.* **6**(3), 214-25 (1952)
- 771.\* Epstein, E. and C. E. Hagen. A kinetic study of the absorption of alkali cations by barley roots. *Plant Physiol.* **27**, 457-74 (1952)
- 772.\* Epstein, E. and S. B. Hendricks. Uptake and transport of mineral nutrients in plant roots. *Geneva Conf. Proc.* **12**, 98-102 (1956)
773. Epstein, E. and J. E. Leggett. Absorption of alkaline earth cations by barley roots; kinetics and mechanism. *Am. J. Bot.* **41**, 785-91 (1954)
- 774.\* Espinasse, P. G. Biology and the bomb. *Nation* **180**, 579-81 (1955)
775. Failla, G. "Statement on Radioactive Fallout" by Advisory Committee on Biology and Medicine. *Amer. Scientist* **46**, 138-50 (1958)
- 776.\* Flocker, W. J. and W. H. Fuller. Availability of calcium in calcareous soils. *Soil Sci. Soc. Am. Proc.* **20**, 387-91 (1956)
- 777.\* Foster, R. F., and J. J. Davis. The accumulation of radioactive substances in aquatic forms. *Geneva Conf. Proc.* **13**, 364-7 (1956)
- 778.\* Fox, B. W., A. Littman, M. I. Grossman and A. C. Ivy. Effects of intragastric irradiation on the gastric acidity in the dog. *Gastroenterology* **24**, 517-34 (1953)
779. Franks, W. R. Differential susceptibility of animals to dust. A critical review. *Arch. Ind. Health* **12**(3), 288-96 (1955)
780. Fretter, V. Experiments with strontium-90 on certain mollusca and polychaetes. *J. Marine Biol. Assoc. (United Kingdom)* **32**, 367-84 (1953)

781. Friedemann, H. C. Effects of irradiation on solids: A bibliography; 4th ed. NP-6237, 65 p (March 1957)
782. Fuller, W. H. and W. J. Flocker. The uptake of radiostrontium by certain crops from calcareous soils. Univ. of Arizona Tech Bull. 130 (1955)
- 783.\* Furth, J. and J. L. Tullis. Carcinogenesis by radioactive substances. AECU-3080, 60 p (1955)
- 784.\* German, L. L. and H. M. Rozendaal. Physical and medical effects of radiation. Elect. Eng. 67, 884-9 (1948)
- 785.\* Gloyna, E. F. Radioactive contaminated laundry waste and its treatment. I. Preliminary experiments with bacterial and yeast suspensions Sewage and Ind. Wastes 26, 777-89 (1954)
- 786.\* Glueckauf, E. Fission product uptake in plants. Paper 7. AERE-SPAR-7 (July 1955)
- 787.\* Goldsmith, H. H. Bibliography on radiation protection. Nucleonics 4, 62-9 (1949)
- 788.\* Goldstein, S. W. Hazards of atomic radiation. J. Am. Pharm. Assoc. Pract. Pharm. Ed. 17, 461, 470 (1956)
- 789.\* Gong, J. K., W. H. Shipman and S. H. Cohn. Uptake of fission products and neutron-induced radionuclides by the clam. Proc. Soc. Exp. Biol. & Med. 95, 451-4 (1957)
- 790.\* Goodgal, S., E. F. Gloyna and D. E. Carritt. Reduction of radioactivity in water. Am. Water Works Assoc. J. 46, 66-78 (1954)
- 791.\* Goodman, J., and J. H. Coleman. Dose rate dependence of KEL-F degradation by ionizing radiation. J. Polymer Sci. 25, 253-6 (1957)
- 792.\* Gray, L. H. Cellular radiobiology. Ann. Rev. Nuclear Sci. 6, 353-422 (1956)
- 793.\* Grosch, D. S. and L. E. LaChance. Fate of radiostrontium fed to habrobracon females. Science 123, 141-2 (1956)
- 794.\* Gross, W. J., et al. The availability of radiostrontium to mammals by way of the food chain. UCLA-259, 29 p (June 18, 1953)
- 795.\* Gross, W. J., J. F. Talyor and J. C. Watson. Factors influencing the metabolism of radiostrontium by animals. USAEC UCLA 274, 3-10 (1954)
- 796.\* Guliakin, I. V. and E. V. Iudintseva. The introduction of radioactive isotopes of strontium, cesium, ruthenium, zirconium and cerium into plants. AERE-Lib/Trans-749. (Transl. from Dokl. Akad. Nauk SSSR 111, 206-9 (1956))
- 797.\* Guliakin, I. V. and E. V. Iudintseva. Supply of radioactive isotopes to the plant by the way of leaves. Akad. Nauk. SSSR Dok. 111, 709-12 (November 21, 1956)

798. \* Guliakin, I. V. and E. V. Iudintseva. Intake of radioactive fission products by plants and their accumulation in the crop during the application of lime, humus, and potash to the soil. *Timiriazovskaia Sel'skokhoz. Akad. Izv.* (2), 121-40 (1957)
799. \* Gustafson, F. G. Absorption of cobalt-60 by leaves of young plants and its translocation through the plant. *Am. J. Bot.* **43**, 157-60 (February 1956)
800. \* Haas, L. L. and G. H. Sandberg. Modification of the depth dose curves of various radiations by interposed bone. *Brit. J. Radiol.* **30**, 19-26 (1957)
801. \* Haldane, J. B. S. Genetical effects of radiation from products of nuclear explosions. *Nature* **176**, 115 (1955)
802. \* Hale, D. H. The atomic bomb and hazardous radiation. *Armed Forces Chem. J.* **3**(5), 18-19, 38, 40 (1949)
803. \* Halperin, J. E. Tests show radioactive products of atomic explosions absorbed by some crop plants. *Crops and Soils* **5**, 29 (1953)
804. \* Hamilton, J. G. The metabolic properties of the fission products and actinide elements. *Rev. Mod. Phys.* **20**, 718-28 (1948)
805. \* Hamilton, J. G. The metabolism of the radioactive elements created by nuclear fission. *New England J. Med.* **240**, 863-70 (1949)
806. \* Hanford Atomic Products Operation. Biology Section. Biology research annual report, 1955. HW-41500 (February 16, 1956)
807. \* Hanford Atomic Products Operation, General Electric Co. Biology research - annual report, 1956. HW-47500, 237 p (January 4, 1957)
808. \* Harley, J. H., E. P. Hardy, Jr., G. A. Welford, I. B. Whitney and M. Eisenbud. Summary of analytical results from the HASL strontium program to June 1956. NYO-4751, 39 p (August 31, 1956)
809. \* Harley, J. H., E. P. Hardy, I. B. Whitney and M. Eisenbud. Summary of analytical results from the HASL strontium program, July - December 1956. NYO-4862, 44 p (March 15, 1957)
810. \* Harper, W. J. Atoms in the dairy industry. *Am. Milk R.* **19**, 24-6 (June 1957)
811. \* Harrison, G. E., W. H. A. Raymond and A. Sutton. The estimation of strontium-90 in the excreta. *Clin. Sci. (London)* **13**, 61-7 (1954)
812. \* Harrison, G. E., W. H. A. Raymond and H. C. Tretheway. The metabolism of strontium in man. Paper No. 2. AERE-SPAR-2 (July 1955)
813. \* Harrison, G. E., W. H. A. Raymond and H. C. Tretheway. The estimation of barium and strontium in biological materials by activation analysis with special reference to the turnover of strontium in man. *Geneva Conf. Proc.* **11**, 156-9 (1956)

- 814.\* Hawaii Marine Lab., Univ. of Hawaii. Radioisotope uptake in marine organisms with special reference to the passage of such isotopes as are liberated from atomic weapons through food chains leading to organisms utilized as food by man. Annual report from 1954-1955. AECU-3079 (September 1, 1955)
- 815.\* Hawthorne, R. Can industry parry the A-bomb? Aviation Age, p 17-19 (January 1951)
816. Healy, J. W. Calculation of maximum, permissible concentration for long-lived radioisotopes. Radiation Research 4, 367-72 (1956)
- 817.\* Hendricks, S. B. and L. A. Dean. Radioisotopes in soils research and plant nutrition. Ann. Rev. Nuclear Sci. 1, 597-610 (1952)
- 818.\* Hevesy, C. D., A. G. Fossberg and J. D. Abbott, eds. Advances in radiobiology (Proc. 5th International Conference on Radiobiology, Stockholm, August 1956). Oliver and Boyd, London (1957)
819. Hiyama, Y. Biological cycle of fission products considered from viewpoint of contamination of marine organisms. Geneva Conf. 13, 368-70 (1956)
- 820.\* Hodges, R. M., *et al.* The strontium content of human bones. UCLA-47, 16 p (November 9, 1949)
- 821.\* Hood, S. L. and C. L. Comar. Metabolism of cesium-137 in rats and farm animals. Arch. Biochem. & Biophys. 45, 423-33 (1953)
- 822.\* Hunger, C. G. Radiation injuries in atomic warfare with stress on fallout. Can. Med. Assoc. J. 76, 394-501 (1957)
- 823.\* Ishigami, R., *et al.* Observations on both the blood picture and bone marrow in atomic bomb sufferers in Nagasaki with special reference to Nishiyama District. NP-304, 24 p; Ind. Hyg. Digest 14, 26 (1950)
- 824.\* Japanese Committee for Compilation of Report on Research in the Effects of Radioactivity. Research in the effects and influences of the nuclear bomb test explosions. Japan Soc. for the Promotion of Sci. Ueno, Tokyo, Vols. I and II, 1824 p (1956)
- 825.\* Jacobson, L. and R. Overstreet. Uptake by plants of plutonium and some products of nuclear fission adsorbed on soil colloids. Soil Sci. 65, 129-34 (1948)
- 826.\* Johns, C. G. The absorption and distribution of radiostrontium ( $\text{Sr}^{90}$ ) and radoruthenium ( $\text{Ru}^{106}$ ) in certain vegetable crops. AECU-3101 (September 1955)
- 827.\* Jonas, H. Calcium translocation in calcium starved peas. AECU-1877 (1952)
- 828.\* Jones, D. C. and H. D. Copp. The metabolism of radiostrontium in adult, young, and rachitic rats. J. Biol. Chem. 189, 509-14 (1951)

829. \* Jornlin, F. M. The atom bomb's effects on plants and soil. *Fertilizer Rev.* **23**(4), 7-11, 14; (5), 7-9, 11-13 (1948)
830. \* Jowsey, J., *et al.* Deposition of strontium-90 in rabbit bones following intravenous injection. *Brit. J. Exptl. Pathol.* **34**, 384-91 (1953)
- 831 Jowsey, J., *et al.* Retention and excretion of strontium-90 by adult rabbits. *Brit. J. Exptl. Pathol.* **36**, 22-6 (1955)
832. \* Jowsey, J., H. A. Sissons and J. Vaughn. The site of deposition of yttrium-91 in the bones of rabbits and dogs. *J. Nuclear Energy* **2**, 168-76 (1956)
833. Kawabata, T. Radiologic contamination of fish. II. Actual state of radiologic contamination in fish and its possible routes on the basis of the findings of the "Bikini Expedition." *Japan J. Med. Sci. and Biol.* **8**, 347-58 (1955)
834. \* Kavin, B., D. H. Copp and J. G. Hamilton. Studies of the metabolism of certain fission products and plutonium. UCRL-812, (August 7, 1950)
835. \* Kehoe, E. J. Atomic bomb effects. *ASTM Bull.* **170**, 16-7 (1950)
836. \* Kellner, A., *et al.* Effect of radiation on bacteria. Symposium on radiation effects on cells and bacteria. *Bact. Rev.* **19**, 22-44 (1955)
837. \* Kiba, T., *et al.* Radioactive substances found on the contaminated fish. *Japan Analyst* **3**, 361-3 (1954)
838. \* Kidman, B., M. L. Tutt and J. M. Vaughn. The retention and excretion of radioactive strontium and yttrium in the healthy rabbit. *J. Path. Bact.* **62**, 209-27 (1950)
839. \* Kidman, B., M. L. Tutt and J. M. Vaughn. The retention of strontium-89, strontium-90 and yttrium-90 in pregnant and lactating rabbits and their offspring. *J. Path. Bact.* **63**, 253-68 (1951)
840. \* Kikuchi, T., G. Wakisaka, M. Suenaga, T. Kono, H. Akagi, H. Goto, T. Matsuki, and Y. Yoshimine. Paper XI. Studies on the metabolism of fission products. III. Radioautographic studies on the localization of radiostrontium and radiocalcium in the bones. *Bull. Inst. Chem. Research, Kyoto University Suppl. Issue*, 99-105 (1954)
841. \* Kimura, K. Analysis of radioactive fallout of the atomic bomb explosion on Bikini. *Radioisotopes (Japan)* **3**(1), 1-4 (1954)
842. \* Kimura, K. Radioactive ashes on the 5th Fukuryu Maru. *Kagaku* **24**, 300-2 (1954)
843. \* Kimura, K. Radiochemical analysis of radioactive dusts. *Proc. Ing. Congr. on peaceful uses of atomic energy. A/Conf.* 8/P/1058 (July 11, 1955)

844. \* Kimura, K., *et al.* Radiochemical analysis of the body of the late Mr. Kuboyama. *Radioisotopes* **4**(2), 22-7 (1956)
845. Kinsman, S. Radiological Health Handbook. Robert A. Taft Sanitary Engineering Center, Cincinnati, PB-121784, 358 p (January 1957)
846. \* Kirby-Smith, J. S. and C. P. Swanson. Appendix by C. W. Sheppard and E. B. Darden, Jr. Effects of fast neutrons from a nuclear detonation on chromosome breakage in *tradescantia*. *Science* **119**, 42-5 (1954)
847. \* Kisielewski, W. E., W. P. Norris and L. A. Woodruff. Effect of BAL on distribution and metabolism of phosphorus-32 and strontium-90. *Proc. Soc. Exptl. Biol. Med.* **77**, 694-6 (1951)
848. \* Knauss, H. J. and J. W. Porter. The absorption of inorganic ions by *Chlorella pyrenoidosa*. *Plant Physiol.* **29**, 229-43 (1954)
849. \* Korotkikh, G. I. Aerosols and their utilization in agriculture. Moskva, Gosdarstvennoe Izdatel'stro Sel'skoshoziaistvennai Literatury, 111 p (1956)
850. Kulp, J. L., W. R. Eckelman and A. R. Schulert. Strontium-90 in man. *Science* **125**, 219-25 (1957)
851. \* Lang, E. P. Report on radioactive contamination of foods. *J. Assn. Off. Agric. Chem.* **38**, 678-82 (1955)
852. \* Lang, E. P. Exposure of foods and foodstuffs to nuclear explosions. *J. Assn. Off. Agric. Chem.* **40**, 544-61 (1957)
853. \* Langham, W. H. Problems of the livestock industry created by atomic explosions (with discussion). *Proc. U.S. Live Stock Sanitary Assn.* **1950**, 48-61 (1951)
854. \* Langham, W. H. and E. C. Anderson. Strontium-90 and skeletal formation. *Science* **126**, 205-6 (1957)
855. \* Lapp, R. E. Atomic bomb explosions - effects on an American city. *Bull. Atomic Sci.* **4**(2), 49-54 (February, 1948)
856. \* Lapp, R. E. The atomic bomb vs. City X. *Wings* **19**(12), 5-130 (August 1949)
857. Lapp, R. E. Papers on fallout. *Bull. Atomic Sci.* **10**(9), 349-51 (November 1954); **11**(2), 45-51 (February 1955); **11**(6), 206-9 (June 1955); **11**(9), 339-43 (November 1955)
858. Lapp, R., J. L. Kulp, W. R. Eckelmann and A. R. Schulert. Strontium-90 in man. *Science* **125**, 933-4 (1957)
859. \* Larson, K. H., J. H. Olafson, J. W. Neel and A. J. Stern. The uptake of radioactive fission products by radishes and Ladino clover from soil contaminated by actual sub-surface detonation fallout materials. UCLA-272 (December 14, 1953)



860. \* Leitch, J. L. Summary of the radiological findings in animals from biological surveys of 1947-1950. UCLA-111 (February 7, 1951)
861. Lengemann, F. W. Comparative metabolism of strontium-89 and calcium-45 by bone growth in vitro. Proc. Soc. Exptl. Biol. Med. **94**, 64-6 (1957)
862. \* Letaret, A. A. Health protection of workers exposed to ionizing radiations. Geneva Conf. Proc. **13**, 159-67 (1956)
863. \* Libby, W. F. Dosages from natural radioactivity and cosmic rays. Science **122**, 57-8 (1955)
864. \* Libby, W. F. What the atom can do to you and for you. U.S. News and World Report, 64-70, 73-77, (May 17, 1957)
865. \* Lisco, H. and M. P. Finkel. Observations on lung pathology following inhalation of radioactive cerium. Federation Proc. **8**, 361 (1949)
866. \* Loeffler, R. K. and V. Thomas. A quantitative study of percutaneous absorption. I. Absorption of radiostrontium chloride in minute quantities through intact and mechanically damaged rat skin. AD-225 (B) (June 15, 1950)
867. \* Luntz, J. D. Radiation safety for a weapons test. Nucleonics **10**(5), 10-3 (1952)
868. \* Lushbaugh, C. C. and J. B. Storer. The correlation of morphologic with metabolic changes in rat skin following exposure to beta (strontium-90) radiation. Am. J. Path. **28**, 556 (1952)
869. MacDonald, N. S., *et al.* Effects of calcium and phosphate in foods on radiostrontium accumulation. J. Nutrition **57**, 555-63 (1955)
870. \* MacDonald, N. S., *et al.* Gastrointestinal absorption of ions. I. Agents diminishing absorption of strontium. UCLA-169, 13 p (November 13, 1951)
871. \* MacDonald, N. S., *et al.* Mechanisms in skeletal accumulation of ions. UCLA-222 (September 11, 1952)
872. \* MacDonald, N. S., *et al.* The skeletal deposition of nonradioactive strontium. UCLA-80, 21 p (July 7, 1950)
873. \* MacDonald, N. S., F. Ezmirlan, P. Spain and C. McArthur. The ultimate site of skeletal deposition of strontium and lead. J. Biol. Chem. **189**, 387-99 (1951)
874. \* MacDonald, N. S., *et al.* The skeletal deposition of nonradioactive strontium. J. Biol. Chem. **188**, 137-43 (1951)
875. Machta, L. and R. J. List. Strontium-90 main hazard Science News Letter **71**, 214 (1957)

- 876.\* Mackie, R. W., J. M. Blume and C. E. Hagen. Histological changes induced in barley plants by radiation from P<sup>32</sup>. *Am. J. Bot.* **39**, 229-237 (1952)
- 877.\* Martell, E. A. The Chicago Sunshine method. Absolute assay of strontium-90 in biological materials, soils, waters, and air filters. U.S. AEC Rept. No. AECU-3262 (May 1956)
- 878.\* Martell, E. A. Strontium-90 concentration data for biological materials, soils, waters and air filters. Univ. of Chicago (USAEC), AECU-3297 (Rev.), 67 p (January 1957)
- 879.\* Martin, D. C. The absorption and translocation of radiostrontium by the leaves, fruits and roots of certain vegetable plants. *Dissertation Abs.* **14**, 1875 (1954)
- 880.\* McDonnell, G. M. Medical aspects of the atomic bomb. *Ordnance*, 308-310 (March-April 1950)
- 881.\* McHenry, J. R. Adsorption and retention of cesium by soils of the Hanford Project. HW-31011 (March 2, 1954)
- 882.\* McHenry, J. R. Adsorption and retention of strontium by soils of the Hanford Project. HW-34499 (February 1, 1955)
883. McHenry, J. R. The adsorption and retention of strontium by a calcareous soil. *Agron. Abs.* **49**, 9 (1957)
884. Menzel, R. G. Competitive uptake by plants of potassium, rubidium, cesium, and calcium strontium, barium from soils. *Soil Sci.* **77**, 419-25 (1954)
885. Menzel, R. G. and I. C. Brown. Removal of radioactivity from soil by leaching. U.S. Dept. Agr. Bimonthly Report, 4 p (March-April 1953)
886. Menzel, R. G. and W. R. Heald. Distribution of potassium, rubidium, caesium, calcium, and strontium within plants grown in nutrient solutions. *Soil Sci.* **80**, 287-93 (October 1955)
887. Menzel, R. G. and W. R. Heald. Strontium and calcium contents of crop plants in relation to exchangeable strontium and calcium in the soil. *Agron. Abs.* **49**, 10 (1957)
888. Middleton, L. J. Absorption and translocation of strontium and caesium by plants from foliar sprays. *Nature* **181**(4619), 1300-3 (May 10, 1958)
- 889.\* Miller, J. R. and R. F. Reitemeier. No title. U.S. Dept. Agri., Soil and Water Conservation Research Div. Research Rept. No. 300 (1957)
- 890.\* Miller, R. W. Delayed effects occurring within the first decade after exposure of young individuals to the Hiroshima atomic bomb. *Pediatrics* **18** 1-18 (1956)

891. \* Milton, G. M. and W. E. Grummitt. Ion-exchange methods for the quantitative separation of the alkaline earths and their application to the determination of strontium-90 in milk ash. Radiochemical procedures for strontium and yttrium. Atom. Energy of Canada, Ltd., CRC-688, 37 p (February 1957)
892. \* Mitlin, N. and P. H. Babers. Action of radiostrontium in the housefly and German cockroach. J. Econ. Entom. **49**, 714-5 (1956)
893. \* Mitsui, S., S. Aso, K. Tensho, K. Kumazawa and K. Meyawaki. Investigations on the radioactive contamination of crop plants as a result of H-bomb detonation. I. Radioactive contamination of crop plants and soils. Soil and Plant Food **1**(1), 15-6 (1955)
894. Mitsui, S., S. Aso, K. Tensho and K. Kumazawa. Investigations on the radioactive contamination of crop plants as a result of hydrogen-bomb detonation. II. Root and foliage uptake of Bikini ash. Soil and Plant Food **1**, 17-8 (1955)
895. \* Moh, C. C., *et al.* Unusual association of two mutant characters in atom-bombed barley. J. Heredity **46**, 35-40 (1955)
896. \* Moh, C. C. and L. Smith. Analysis of seedling mutants (spontaneous, atomic bomb radiation - and X-ray induced) in barley and Durum wheat. Genetics **36**, 629-40 (1951)
897. \* Moh, C. C. and L. Smith. Three coincidental changes in atom-bombed barley. J. Heredity **43**, 183-8 (1952)
898. Morgan, K. Z., E. S. Snyder and M.R. Ford. Maximum permissible concentration of radioisotopes in air and water for short period exposure. Geneva Conf. Proc. **13**, 139-58 (1956)
899. Morgan, K. Z. and C. P. Straub. External and internal exposures to ionizing radiation and maximum permissible concentration of radioactive contamination in the air and water following an atomic explosion. USAEC Tech. Info Ser., Oak Ridge, AECU **2332**, 3-19 (1952)
900. \* Muller, H. G. Comments on the genetic effects of radiation on human populations. J. Heredity **46**, 199-200 (1955)
901. Muller, H. J. Genetic damage produced by radiation. Bull. Atomic Sci. **11**, 210-12 (1955)
902. \* Nagasawa, K., *et al.* Radioactivity contamination in foodstuffs effected by atomic- and hydrogen-bomb explosion. II through VI. Eisei Shikenjo Hokoku **74**, 201-32 (1956)
903. \* Nagasawa, K., I. Kawashiro, S. Kawamura, Y. Takenaka and S. Nishizaki. Radiochemical studies on radiocontaminated rice cropped in Niigata Prefecture in 1954. Bull. of Nat. Hyg. Lab., Tokyo, No. 73, 187-90 (1955)

- 904.\* Nakaidzumi, - . The radioactivity of the atomic bomb from the medical point of view. Tokyo Imperial University, NP-302, 10 p Ind. Hyg. Dig. 14, 24-5 (1950)
905. National Academy of Sciences. The biological effects of atomic radiation. Summary reports. National Research Council, Washington, D.C., 108 p (1956)
- 906.\* National Academy of Sciences. The biological effects of atomic radiation. AD-109 062, AD 109 063. Rept. No. NP-6016 and 6017.
- 907.\* National Research Council. The biological effects of atomic radiation. A report to the public. Washington, 40 p (1956)
- 908.\* National Research Council. The biological effects of atomic radiation. Summary reports. Washington, 108 p (1956)
- 909.\* Nature (London). Biological hazards of radiation. Nature 175(4460), 695-7 (April 23, 1955)
- 910.\* Neel, J. W., *et al.* Soil plant interrelationships with respect to the uptake of fission products. UCLA-247, 4-44 (1953)
- 911.\* Neel, J. W. and W. J. Schull. The effect of exposure to the atomic bombs on pregnancy termination in Hiroshima and Nagasaki. National Academy of Sciences - National Research Council, 241 p (1956)
- 912.\* Nesbitt, J. B., *et al.* Removal of radioactive strontium from water by phosphate coagulation. NYO 4435, 3-128 (1952)
- 913.\* Neuman, W. F. and B. J. Mulryan. The deposition of uranium in bone. J. Bio. Chem. 175, 705-19 (September 1948)
- 914.\* Neuman, W. F., M. W. Neuman, E. R. Main and B. J. Mulryan. The deposition of uranium in bone; ion competition studies. J. Bio. Chem. 179(1), 325-33, 335-40, 341-8 (1949)
915. Newcombe, H. B. Magnitude of biological hazard from strontium-90. Science 126, 549-51 (1957)
- 916.\* Nilan, R. A. and C. C. Moh. Mutant line of barley induced by atomic bomb radiation; effect of partial ovule sterility on the inheritance of *cream* seedlings. J. Heredity 46, 49-52 (1955)
- 917.\* Nishita, H., *et al.* Fixation and extractability of fission products contaminating various soils and clays: I. Strontium-89, strontium-90, yttrium-91, rubidium-106, cesium-137 and cerium-144. UCLA-282, 32 p (February 23, 1954)
- 918.\* Nishita, H., *et al.* The influence of soil organic matter on the uptake of strontium-90 by barley and tomato plants. UCLA, School of Medicine (USAEC). UCLA-349, 42 p (October 1955)

919. Nishita, H., *et al.* Fixation and extractability of fission products contaminating various soils and clays - strontium-90, yttrium-91, rubidium-106, cesium-137, cerium-144. *Soil Sci.* **81**, 317-26 (1956)
920. Nishita, H., *et al.* Influence of soil organic matter on the mineral uptake by barley seedlings. *Soil Sci.* **82**, 307-18 (1956)
921. Nishita, H., A. J. Steen and K. H. Larson. The release of strontium-90 and cesium-137 from Vima loam upon prolonged cropping. Atomic Energy Project, UCLA, Contract AT-04-1-GEN-12. UCLA-380, 32 p (November 6, 1956)
922. \* Nishita, H. and K. H. Larson. Summary of certain trends in soil-plant relationship studies of the biological availability of fall-out debris. UCLA, School of Medicine (USAEC). UCLA-401, 68 p (July 1957)
923. \* Oak Ridge National Laboratory. Health Physics Division semi-annual progress report for period ending January 31, 1955. ORNL-1860 (May 9, 1955)
924. \* Oliver, R. and J. Vaughan. An attempt to assess the dosage of strontium-90 received by young rabbit bone. *Brit. J. Radiol.* **29**, 668-72 (1956)
925. \* Ota, M., *et al.* Contamination of grapes by radioactive substances. *Soil and Plant Food* **1**(1), 43-4 (1955)
926. \* Oughterson, A. W. and S. Warren, eds. Medical effects of the atomic bomb in Japan. Nat. Nuclear Energy Series Div. VIII, Vol. VIII. McGraw-Hill, N.Y., 477 p (1956)
927. \* Pace, F. C. Effects of atomic bomb radiations on human food. *Can. J. Public Health* **47**, 113-41 (April 1956)
928. \* Pagan, C. and M. P. Morris. Derris deposits, fate of deposits on young bean plants. *Agr. and Food Chem.* **1**, 580-58 (July 8, 1953)
929. \* Parker, H. M. Effects of reactor accidents on plant and community. *Arch. Ind. Health* **13**, 441-2 (1956)
930. \* Parker, H. M. Radiological Sciences Dept. research and development activities quarterly progress report, January - March 1956. HW-42403, 33 p (April 13, 1956)
931. \* Parker, H. M., and J. W. Healy. Environmental effects of a major reactor disaster. Geneva Conf. Proc. **13**, 106-9 (1956)
932. \* Pirson, A. and K. Kellner. Physiologische wirkungen des rubidiums. *Ber. Deutsch. Bot. Ges.* **65**, 276-86 (1952)
933. \* Poliakov, Iu. A. The problem of contamination of soils and crops with the products of radioactive fission (a survey of the principal literature data). *Pochvovedenie* **8**, 57-73 (August 1956)

- 934.\* Porter, J. W. and H. J. Knauss. Inhibition of growth of *Chlorella pyrenoidosa* by  $\beta$ -emitting radioisotopes. *Plant Physiol.* **29**, 60-3 (1954)
- 935.\* Rediske, J. H., J. F. Cline and A. A. Selders. The adsorption of fission products by plants. HW-36734 (May 17, 1955)
936. Rediske, J. H. and F. P. Hungate. The absorption of fission products by plants. *Geneva Conf. Proc.* **13**, 354-6 (1956)
937. Rediske, J. H. and A. A. Selders. Absorption and translocation of strontium by plants. *Plant Physiol.* **28**, 594-605 (1953)
- 938.\* Rediske, J. H. and A. A. Selders. The uptake and translocation of cesium by plants. HW-35174 (September 15, 1953)
939. Rediske, J. H. and A. A. Selders. Uptake and translocation of yttrium by higher plants. *Am. J. Bot.* **41**, 238-42 (1954)
- 940.\* Reitemeier, R. F. No title. Great Britain, AERE Rept. SPAR 12, 1955.
- 941.\* Revelle, R., *et al.* Oceanography, fisheries, and atomic radiation. *Science* **124**(3210), 13-16 (July 6, 1956)
- 942.\* Ridenour, L. N. How effective are radioactive poisons in warfare? *Bull. Atom. Sci.* **6**(7), 199-224 (July 1950)
- 943.\* Rinehart, R. W., *et al.* Residual contamination of plants, animals, soil and water of the Marshall Islands one year following Operation Castle fallout. NRDL-454, 45 p (August 12, 1955)
- 944.\* Röhr, E. The effect of the atomic bomb on man and animals. *Hippocrates* **19**, 43-4 (1948)
- 945.\* Romney, E. M., G. V. Alexander, G. M. LeRoy, W. A. Rhoads, J. W. Neel and K. H. Larson. Effects of calcium and strontium on plant uptake of strontium-90 and stable strontium from nutrient solutions and soils. UCLA-374 (July 15, 1956)
946. Romney, E. M., *et al.* Plant uptake of strontium-90, yttrium-91, rubidium-106, cesium-137 and cerium-144 from soils. *Soil Sci.* **83**(5), 369-76 (May 1957)
- 947.\* Romney, E. M., W. A. Rhoads and K. Larson. Plant uptake of strontium-90, rubidium-106, cesium-137 and cerium-144 from three different types of soil. USAEC, UCLA-294, 28 p (1954)
- 948.\* Romney, E. M. and S. J. Toth. Plant and soil studies with radioactive manganese. *Soil Sci.* **77**, 107-17 (February 1954)
- 949.\* Rosenthal, H. L. Uptake of calcium-45 and strontium-90 from water by fresh-water fishes. *Science* **126**, 699-700 (October 11, 1957)
950. Russell, R. S. and R. P. Martin. Use of radioactive phosphorus in plant nutritional studies *Nature* **163**, 71-2 (1949)

951. Russell, R. S. and G. M. Milbourn. Rate of entry of radioactive strontium into plants from soil. *Nature* **180**(4581), 322-4 (August 17, 1957)
952. \* Russell, R. S., H. M. Squire and R. P. Martin. Effects of Operation Hurricane on plants and soils. *AERE (Gt. Brit.) SPAR/3*, 74 p (1955)
953. \* Russell, W. L., *et al.* Relative effectiveness of neutrons from a nuclear detonation and from a cyclotron in inducing dominant lethals in the mouse. *Amer. Nat.* **88**, 269-86 (1954)
954. \* Rust, J. H. Genetic embryologic and neonatal problems related to ionizing radiation of interest to veterinarians. *J. Am. Vet. Med. Assn.* **119**, 103-7 (1951)
955. \* Rygh, O. Trace elements. 1. Importance of strontium, barium, and zinc (in the animal organism) *Bull. Soc. Chem. Biol.* **31**, 1052-61 (1949)
956. \* Saal, H. What is this strontium-90 business? *Am. Milk Rev.* **18**, 30, 32 and 34 (1956)
957. Saiki, M. On the radioelements of fishes contaminated by the nuclear bomb test. *Japan Analyst* **7**(7), 443-9 (1957)
958. \* Saiki, M., S. Okano and T. Mori. The radioactive material in the radiologically contaminated fishes caught in the Pacific Ocean in 1954. *Bull. Japan. Soc. Sci. Fisheries* **20**, 902-6 (1955)
959. Sasaki, R. Biological cycles of fission products in agriculture in Japan. *Geneva Conf. Proc.* **13**, 357-9 (1956)
960. \* Sayre, J. D. Some hidden secrets of plant nutrition accumulation of radio isotopes in corn leaves. *Fertilizer* **28**(1), 8-9 (1952)
961. \* Schaefer, M. B. The effects of nuclear explosions on marine biology. Proj. 2.5 - Operation Wigwam. *ITR-1063* (May 1955)
962. \* Schwebel, A. Report on radioactivity. *J. Assn. Off. Agri. Chem.* **38**, 677 (1955)
963. \* Schjeide, O. A., *et al.* Notions on sensitivity of cells to radiation. *UCLA., School of Medicine (USAEC), UCLA-348*, 19 p (October 1955)
964. \* Schnitt, H. P. Effects of nuclear explosions on frozen foods. Proj. 32.2, Operation Teapot. *WT-1215* (March 1956)
965. \* Schubert, J. Estimating radioelements in exposed individuals. *Nucleonics* **8**(2), 13-28 (1951); **8**(3), 66-78 (1951); **8**(4), 59-67 (1951)
966. \* Selders, A. A., J. F. Cline and J. H. Rediske. The adsorption by plants of  $\beta$ -emitting fission products from the Bravo soil. *HW-40289* (December 20, 1955)

967. \* Selders, A. A., J. H. Rediske and R. F. Palmer. The absorption and translocation by plants of radioactive elements from "Jangle" soil. HW-27620 (February 16, 1953)
968. \* Shidei, T., S. Okada and K. Yoshikawa. On the contamination of seedlings at nursery by some radiation substances contained in rainfall. Jap. Forestry Soc. J. **39**(5), 183-4 (May 1957)
969. \* Shipman, T. L. Strontium-90, a mountain or a molehill? Milk Plant Mo. **46**, 21-4 (September 1957), 26 (October 1957)
970. Sievert, R. M., S. Gustafsson and C. G. Sylander. Increase in gamma-radiation from powdered milk and beef. Nature **178**, 854-5 (1956)
971. \* Singleton, W. R. The effect of chronic gamma radiation on endosperm mutations in maize. Genetics. **39**, 587-603 (September 1954)
972. \* Singleton, W. R. Symposium of effects of radiation and other deleterious agents on embryonic development, Oak Ridge, Tenn., April 20-21, 1953. J. Heredity **46**, 291-2 (1955)
973. \* Smith, L. Effects of atomic bomb radiations and X-rays on seeds of cereals. J. Heredity **41**, 125-30 (1950)
974. Sowden, E. M. and S. R. Stitch. Trace elements in human tissue. 1. A semiquantitative spectrographic survey; 2. Estimation of the concentrations of stable strontium and barium in human bone. Biochem. J. (London) **67**, 97-103, 104-9 (1957)
975. \* Sparrow, A. H. and E. Christenson. Tolerance of certain higher plants to chronic exposure to gamma radiation from cobalt-60. Science **118**, 697-8 (December 4, 1953)
976. \* Spector, W. S. Handbook of Biological Data. National Research Council, Project 7158. WADC-TR-56-273, 620 p (October 1956)
977. \* Spencer, J. L. and A. F. Blakelee. Induced pollen lethals from seeds of dature stramonium exposed to radiation from a nuclear detonation. Proc. Natl. Acad. Sci. **40**, 441-6 (1954)
978. \* Spikes, J. O., R. Lowry and J. S. Rieske. Inhibition of photochemical activity of isolated chloroplasts. Arch. Biochem. & Biophys. **55**, 25-37 (1955)
979. \* Spinks, J. W. T., *et al.* Lethal effects of absorbed radioisotopes on plants. Can. J. Research **26C**, 249-52 (1948)
980. \* Spooner, G. M. Observations on the absorption of radioactive strontium and yttrium by marine algae. J. Marine Biol. Assoc. (U.K.) **28**, 587-625 (1949)
981. Stanton, W. R. and W. K. Sinclair. Effect of high concentration of phosphorus-32 on growth of the potato. Nature **167**, 234-5 (1951)
982. \* Stefanini, M. Role of calcium in the coagulation of blood. Acta. Med. Scand. **136**, 250-66 (1950)



983. Stokinger, H. E. and S. Laskin. Air pollution and the particle size toxicity problems. *Nucleonics* **6**, 15-31 (1950)
984. Stokinger, H. E., *et al* . Lobar deposition and retention of inhaled insoluble particulates. *Arch. Ind. Hyg. & Occ. Med.* **4**, 346-53 (1951)
985. \* Storer, J. B., and W. H. Langham. Quantitative biological methods for studying radiation effects in mammals. AECU-3099 (1954)
986. \* Sutow, W. W. Summary of medical studies on Hiroshima children exposed to the atomic bomb, 1951-1953. NYO-4478
987. \* Swanson, C. A. and J. B. Whitney. The translocation of foliar-applied phosphorus-32 and other radioisotopes in bean plants. *Am. J. Bot.* **40**, 816-23 (1953)
988. \* Takase, A. and K. Yamada. 2 Papers. 1. Distribution of radioactivity in various tissues of fish, and group separation of radioactive elements. 2. Separation of radioactive elements in the muscle of skipjack by ion exchange resin and confirmation of the presence of radioactive zinc. *Bull. Inst. Pub. Health (Tokyo)* **4**(3), 17-26 (1955)
989. \* Tanidazawa, M. and T. Ishihara. Radioactive elements found in plants contaminated by radioactive rain. *Radioisotopes (Japan)* **3**(1), 21-2 (1954)
990. \* Thomas, H. A. The public health implications of radioactive fallout in water supplies. *Am. J. Public Health & Nations Health* **46**, 1266-74 (1956)
991. \* Thornton, P. A., *et al* . Intestinal transit and skeletal retention of strontium-90 and yttrium-90 in the chick. *Poultry Sci.* **35**, 1055-60 (1956)
992. \* Tobias, C. A., P. P. Weymouth, L. R. Wasserman and G. C. Stapleton. Some biological effects due to nuclear fission. *Science* **107**, 115-8 (1948)
993. \* Tullis, J. L. Radioresistant cells in certain radioresistant tissues of swine exposed to atomic bomb radiations. *Arch Path.* **48**, 171-7 (1949)
994. Turekian, K. and J. L. Kulp. Strontium content of human bones. *Science* **124**, 405-7 (1956)
995. \* Ungar, G. and E. Damgaard. Inhibition of inflammatory response in  $\beta$ -ray irradiated skin. *Proc. Soc. Exptl. Biol Med.* **87**, 383-6 (1954)
996. \* University of California at Los Angeles, Atomic Energy Project. Quarterly progress report for period ending June 30, 1956 and September 30, 1956. Contract AT-04-1-GEN-12. UCLA-371, 112 p, July 1, 1956; UCLA-379 (October 1, 1956)

997. \* University of Tennessee. Agricultural research program. Semi-annual progress report for January 1, 1954 - June 30, 1954. ORO-133 (December 1954)
998. \* University of Tennessee. Agricultural research program. Semi-annual progree report, 65 p (January 1, 1956 - June 30, 1956) Contract AT-40-1-GEN-242. ORO-160
999. \* University of Tennessee. Agricultural research program. Semi-annual progress report for July 1, 1956 - December 31, 1956. Contract AT-40-1-GEN-242. ORO-163
1000. \* University of Utah, Radiobiology Laboratory. Annual progress report. AECU-3522, 177 p (March 31, 1957)
1001. \* University of Washington, Applied Fisheries Laboratory. A radiological study of Rongelap Atoll, Marshall Islands, during 1954-1955. Contract AT(45-1)540. UWFL-42 (August 15, 1955)
1002. \* University of Washington, Applied Fisheries Laboratory. Radiobiological resurvey of Rongelap and Ailinginae Atolls, Marshall Islands, October - November 1955. UWFL-43, December 30, 1955
1003. \* U.S. Atomic Energy Commission. Radioactive isotopes in agriculture. USAEC, TID 7512, 414 p (January 1956)
1004. U.S.S.R. Academy of Medical Science. Data on toxicity of radioactive materials: I. Cesium, strontium, ruthenium, and radon. Institute of Sanitation and Occupational Disease, Akademia Nauk SSSR (1957)
1005. \* Van Duzer, R. M. and E. J. Burger. Japanese appraisal of atomic bomb damage to Hiroshima utility system. Elec. World, 98-103 (November 1947)
1006. \* Van Middlesworth, L. Radioactivity in thyroid glands following nuclear weapons tests. Science **123**, 982-3 (June 1, 1956)
1007. Ward, A. H. Retention and excretion of radiostrontium in monkeys. J. Nuclear Energy **5**, 192-202 (1957)
1008. \* Ward, A. H. Retention and toxicity of radiostrontium in monkeys. UNESCO/NS/RIC/142, Pergamon Press, Ltd., 9 p (1957)
1009. \* Warren, S. and R. H. Draeger. The pattern of injuries produced by the atomic bombs at Hiroshima and Nagasaki. U.S. Naval Med. Bull. **46**, 1349-53 (1946)
1010. Wasserman, R. H. Dietary calcium levels and retention of radiostrontium in the growing rat. Science **126**, 1180-2 (December 6, 1957)
1011. \* Weiss, H. V., *et al.* Residual contamination of plants, animals, soil and water of the Marshall Islands two years after Operation Castle fallout. NRDL-455, 62 p (August 15, 1956)

1012. White, M. R. and E. L. Dobson. California cattle thyroid activity associated with fallout, 1955. UCRL-3355 (March 28, 1956)
- 1013.\* Wiebe, H. H. and P. J. Kramer. Translocation of radioactive isotopes from the various regions of roots of barley seedlings. *Plant Physiol.* **29**, 342-8 (1954)
- 1014.\* Witten, V. H., E. W. Brauer, V. Holmstion and R. Loevinger. Erythema effects of a pure beta emitter (strontium-90) on human skin. New York University Postgraduate Medical School, New York City.
- 1015.\* Yamada, Y., *et al.* Measurement of radioactivity in contaminated crops. *Soil and Plant Food* **1**(1), 25-6 (1955)
- 1016.\* Yamamoto, D. Goldschmidt's classification of elements and radioactive isotopes liable to deposit in the bone. *Kagaku (Science)* **25**, 261 (1955)
- 1017.\* Yatazawa, M. and T. Ishihara. Radioactive contamination of plants in Japan covered with fallout from H-bomb detonated in March-May 1954 at Bikini Atoll. I Distribution of deposited radioactivity. II. Radioactive elements of contaminated plants. *Soil and Plant Food* **1**, 21-24 (1955)
- 1018.\* Yatazawa, M. and Y. Yamazaki. Absorption of fission products by plants. Part V. Absorption of gross fission products. *Soil and Plant Food* **2**, 158-63 (1956)
- 1019.\* Yoshii, G., N. Watabe and Y. Okada. Biological decontamination of fission products. *Science* **124**, 320-1 (1956)
- 1020.\* Zemlyanoi, A. G. Formation of bone growth during radiation sickness. *Med. Radiol.* **1**(5), 72-4 (1956)

G. PROPERTIES (PHYSICAL, CHEMICAL, NUCLEAR, RADIOLOGICAL)

1021. Anonymous. ICAO Standard Atmosphere Extension. Jet Propulsion 26(12), 1097 (December 1956)
- 1022.\* Anonymous. Properties of metals at stratospheric heights. Aircr. Eng. 20, 207-14 (1948)
- 1023.\* Abriss, A., J. J. Reilly and E. J. Tuthill. Separation of cesium and strontium from calcined metal oxides as a process in diposal of high level waters. BNL-453 (April 1957)
1024. Adams, C. E., N. H. Farlow and W. R. Schell. The composition, structures, and origins of radioactive fallout particles. Naval Radiological Defense Laboratory Report, NRDL-TR-209 (February 3, 1958)
1025. Appen, A. A. Relation between the properties and constitution of glasses. III. Behavior and properties of alkaline-earth metal oxides in silicate glasses. J. Appl. Chem. USSR 24, 1273-80 (1951)
- 1026.\* Auer, K. F. Organic glass-like materials. Ceramic Age, 183-6 (April 1948)
1027. Baerg, A. P. and R. M. Bartholomew. Yields in uranium-235 thermal neutron fission. Can. J. of Chem. 35, 980-5 (1957)
- 1028.\* Bateman, R. L. and D. T. Ewing. The electrical conductance of strontium chloride and strontium bromide in ethanol-water mixtures. J. Am. Chem. Soc. 70, 2137-40 (1948)
- 1029.\* Bender, P. and R. A. Shrehlow. The solubility of cesium and rubidium dichloriodides in hydrochloric acid solutions. J. Am. Chem. Soc. 70, 1995 (1948)
- 1030.\* Bhattacharjee, S. K., B. Waldman and W. C. Miller. Energy determination of Cesium-137 K conversion electrons. AD-37746. 40 p., Tech. Rept. No. 4 (Contract NG-ori-83 T.O.2)
1031. Bigeleisen, J. The relative reaction velocities of isotopic molecules. J. Chem. Phys. 17, 675-8 (August 1949)
1032. Blewett, J. P., H. A. Liebhafsky and E. F. Hennelly. The vapor pressure and rate of evaporation of barium oxide. J. Chem. Phys. 7, 478-84 (1939)
1033. Blomeke, J. O., and M. F. Todd. Uranium-235 fission-product production as a function of thermal neutron flux, irradiation time, and decay time. I. Atomic concentrations and gross totals. Oak Ridge National Laboratory, Report ORNL-2127, Part I, Volume 1 (August 19, 1957)
1034. Bolles, R. C. and N. E. Ballou. Calculated activities and abundances of uranium-235 fission products. U.S. Naval Radiological Defense Laboratory Rept. No. NRDL-456 (August 30, 1956)

1035. Brewer, L. The thermodynamic properties of the oxides and their vaporization processes. Chem. Rev. **52**, 1-76 (1953)
- 1036.\* Brewer, L. and D. F. Mastick. The stability of gaseous diatomic oxides. J. Chem. Phys. **19**, 834-43 (1951)
1037. Brewer, L. and A. W. Searcy. High temperature chemistry. Ann. Rev. Phys. Chem. **7**, 259-86 (1956)
1038. Brown, F. Yield of cesium-137 in the pile neutron fission of natural uranium. J. Inorg. Nuclear Chem. **1**, 248-52 (1955)
1039. Bunney, L. R. and N. E. Ballou. The chemical species of the elements resulting from an atomic bomb detonation in air. Final Report. U.S. Naval Radiological Defense Laboratory, AD-325(c), 32 p (May 25, 1951)
1040. Bunney, L. R. and N. E. Ballou. An estimate of the predominant chemical species resulting from a shallow underwater burst of an atomic bomb. USNRDL-435 (February 5, 1954)
- 1041.\* Callaway, J. and E. L. Hasse. Electron energy bands in cesium. Tech. Rept. No. 6, Contract Nonr 84006. TAB No. U57-1, AD 133 190, Div. 25
- 1041a. Campbell, I. E. Editor. High temperature technology, John Wiley & Sons, Inc., New York (1956)
- 1042.\* Carlson, T. E. and L. S. Wells. Hydrothermal preparation of some strontium silicates. U.S. Bur. Standards J. Research **51**(2), 73-80 (August 1953)
1043. Carter, P. E. Separation of long-lived fission products. AERE (Gt. Brit.) Rept No. C/R 1231, 51-58 (1953)
- 1044.\* Chackett, K. F. Nuclear reactions at high energies. I. Experimental. J. Roy. Inst. of Chem. **81**, 616-28 (1957)
1045. Claassen, A. and C. F. Veenemans. Vapor pressure of barium oxide, strontium oxide, calcium oxide, and their mixtures from rate of evaporation measurements. Z. Physik **80**, 342-51 (1933)
- 1046.\* Clusius, K. and H. Stern. Ergebnisse der Tieftemperaturforschung. XII. Schmelzwärme des caesiums. Z. angewandte Physik **6**(5), 194-6 (1954)
- 1047.\* Coughlin, J. P. Contributions to the data on theoretical metallurgy. XII. Heats and free energies of formation of inorganic oxides. U.S. Bur. Mines Bull. 542 (1954)
- 1048.\* Cunninghame, J. G. The mass-yield curve for fission of natural uranium by 14 MeV neutrons. J. of Inorg. and Nuclear Chem. **5**, 1-5 (1957)
1049. Drummond, G. and R. F. Barrow. Thermochemical dissociation energies of gaseous calcium, strontium and barium oxides. Trans. Faraday Soc. **47**, 1275-7 (1951)

- 1050.\* Eastwood, W. S. Cesium-137 and its use. AERE C/R 1231
1051. Fields, P. R., M. H. Studier, H. Diamond, J. F. Mech, M. G. Inghram, G. L. Pyle, C. M. Stevens, S. Fried, W. M. Manning, A. Ghiorso, S. G. Thompson, G. H. Higgins, and G. T. Seaborg. Transplutonium elements in thermonuclear test debris. Phys. Rev. **102**, 180-2 (1956)
- 1052.\* Finbak, C. and O. Hassel. Diffraction photographs taken in the characteristic X radiations of atoms in the crystal itself. Norsk Geol. Tids. **16**, 2 p (1936)
1053. Glassner, A. The thermochemical properties of the oxides, fluorides, and chlorides to 2500°K. Argonne National Laboratory Report ANL-5750 (1957)
- 1054.\* Glendenin, E. P. and P. R. Metcalf. 1. Estimation of the half-life of 33-year cesium-137. 2. Mass assignment of 33-year cesium-137. Natl. Nuclear Eng. Ser. Div. IV, **9**
1055. Greendale, A. E. and N. E. Ballou. Physical state of fission product elements following their vaporization in distilled water and seawater. USNRDL-436 (February 16, 1954)
- 1056.\* Grove, G. R. Measurement of cesium-137 and cobalt-60  $\gamma$  radiation with a pressure ionization chamber. J. Res. Natl. Bur. Standards **48**, 147-51 (1952)
1057. Grummitt, W. E. and G. M. Milton. The independent yields of  $^{140}\text{La}$ ,  $^{90}\text{Y}$ , and  $^{91}\text{Y}$  in the thermal neutron fission of  $^{235}\text{U}$  and  $^{233}\text{U}$ . J. of Inorg. and Nucl. Chem. **5**(2), 93-104 (1957)
- 1058.\* Heintze, J. Determining the polarization of the  $\beta$  particles of strontium-90 and yttrium-90. Zeit. fur Physik **148**, 560-3 (1957)
1059. Herrmann, G. On the vapor pressure of barium oxide. Z. Physik. Chem., (B), **35**, 298-308 (1937)
- 1060.\* Hilsenrath, J. and C. W. Beckett. Tables of thermodynamic properties of argon-free air to 15,000°K. AEDC-TN-56-12, Natl. Bur. Standards, 45 p, September 1956
- 1061.\* Hirschfelder, J. O. and J. L. Magee. Thermodynamic properties of air at high temperatures. MDDC-590, 50 p (July 18, 1945)
- 1062.\* Hochanadel, C. J. and S. C. Lind. Radiation chemistry. Ann. Rev. Phys. Chem. **7**, 83-106 (1956)
1063. Honig, R. E. and J. Drowert. Vaporization of compounds and alloys at high temperature. AD-110 374. Tech. Note No. 1; AFOSR-TN-56-555
1064. Hunter, H. F. and N. E. Ballou. Fission product decay rates. Nucleonics **9**(5), C-1 to 5 (November 1951)

- 1065.\* Jones, W. H. Bombardment energy and fission product yield pattern; protons on thorium-232, uranium-233, and thorium-230. Emory University (USAEC), ORO-162, 20 p (1956)
- 1066.\* Katcoff, S. New barium and cesium isotopes 12.0d barium-131, 12.2d cesium-131 and long-lived barium-131. Phys. Rev., 1160 (December 1947)
1067. Katcoff, S., D. A. Miskel and C. W. Stanley. Ranges in air and mass identification of plutonium fission fragments. Phys. Rev. **74**, 631-8 (1948)
1068. Kennedy, G. C. Properties of water. Part I. Pressure-volume-temperature relations in steam to 1000° and 100 bars pressure. Am. J. Sci. **255**, 724-30 (1957)
- 1069.\* Kubaschewski, O. and J. A. Catterall. Thermochemical Data of Alloys. Pergamon Press, London-New York, 200 p (1956)
1070. Lange, N. A., ed. Handbook of chemistry, 9th ed. Handbook Publishers, Inc., Sandusky, Ohio (1956)
1071. Langer, L. M. and R. D. Moffat. A precise determination of the energy of the cesium-137  $\gamma$  radiation. Phys. Rev. **78**, 74-5 (1950)
- 1072.\* Liebhafsky, H. A. and A. F. Winslow. Cesium chromate photo-tube pellets. J. Appl. Phys., 1128-32 (December 1947)
- 1073.\* Loveridge, B. A. A method for the determination of radiocalcium and radiostrontium in effluent. AERE-C/R-1902 (March 1956)
- 1074.\* McSweeney, E. E. Organic coatings for metals. Plating, 340-43 (April 1948)
- 1075.\* Meem, J. L. and F. Marenshein. Coincidence and absorption measurements on cesium-134, iodine-124, gold-199 and calcium-45. Phys. Rev. **76**(3), 328-32 (1949)
1076. Mellor, J. W. A Comprehensive Treatise on Inorganic and Theoretical Chemistry. Vol. V, Chap. XXXII. Boron; Vol. III, Chap. XXIV, The Alkaline Earths. Longmans, Green & Co., Ltd., London (1946)
- 1077.\* Miller, C. F. Proposed decay schemes for some fission-products and other radionuclides. NRDL-TR-160, 118 p (May 27, 1957)
1078. Moore, G. E., H. W. Allison, and J. D. Struthers. The vaporization of strontium oxide. J. Chem. Physics **18**, 1572-9 (1950)
1079. Morris, D. F. C. The lattice energies of some oxides and the affinity of oxygen for two electrons. Proc. Roy Soc. (London) **242**, 116-21 (1957)
1080. National Advisory Committee for Aeronautics. Standard Atmosphere - tables and data for altitudes to 65,800 feet. Rept. 1235. Washington, D. C. (1955)

1081. Nier, A. O. A redetermination of the relative abundances of the isotopes of neon, krypton, rubidium, xenon and mercury. *Phys. Rev.* **79**(3), 450-4 (August 1950)
- 1082.\* Osoba, J. S. The forbidden transition of yttrium-91 to cesium-137. *Phys. Rev.* **76**, 345-9 (1949)
- 1083.\* Paxton, H. C. and G. A. Graves. Critical masses of fissionable metals as basic nuclear safety data. LA-1958 (April 1956)
1084. Prasad, S. and K. P. Srivastava. Chemistry of beryllium, Part 1. Formation of beryllates. *J. Indian Chem. Soc.* **33**, 791-5 (1956)
1085. Quill, L. L. The Chemistry and Metallurgy of Miscellaneous Materials: Thermodynamics. McGraw-Hill Book Co., New York (1950)
1086. Reed, G. W. Uranium-235 thermalneutron fission yields at masses 90 and 91. *Phys. Rev.* **98**, 1327-9 (1955)
- 1087.\* Rudstam, G. Nuclear reactions induced by high energy particles. *Svensk Kemisk Tidskrift* **69**(8), 378-93 (1957)
- 1088.\* Schiffer, J. P. Tables of charged particle penetrabilities. Argonne National Laboratory (USAEC), ANL-5739 (June 1957)
1089. Seidell, A. Solubilities of Inorganic and Metal Organic Compounds, 3rd ed., D. Van Nostrand Co., Inc., New York (1940)
- 1090.\* Simnod, M. T. The application of radioactive tracers to the study of metal solution reactions. *J. Met.* **188**(1), 1220 (October 1950)
- 1091.\* Slater, J. C. Structure and polarization of atoms and molecules. *Elec. Eng.* **69**(10), 872-5 (October 1950)
- 1092.\* Stein, W. E. Velocities of fragment pairs from uranium-233, uranium-235 and phosphorus-239 fission. *Phys. Rev.* **108**(2), 94-98 (1957)
- 1093.\* Tripp, H. P. and B. W. King. Thermodynamic data on oxides at elevated temperatures. *J. Am. Ceram. Soc.* **38**, 432-7 (1955)
- 1094.\* Trischka, J. Electric dipole moments of the lower vibrational states of molecular CsF and CsCl. *J. Chem. Phys.* **25**(4), 784-5 (October 1956)
- 1095.\* Weidenburner, J. W. Thermodynamic properties of air at high temperature. AD 96301. Tech. Note No. AFSWC-TN-56-48
1096. Wiles, D. M. and R. H. Tomlinson. Half-life of cesium-137. *Phys. Rev.* **99**, 188 (1955)
- 1097.\* Wiles, D. M. and R. H. Tomlinson. Half-life of strontium-90. *Can. J. Phys.* **33**, 133-7 (1955)
- 1098.\* Wolschrijn, R. A. Isolation of carrier-free cesium-137 from fission products. JENER Rept. No. 49, 23 p (1957)



- 1099.\* Woolley, H. W. Thermodynamic functions for atomic ions.  
AFSWC-TR-56-34, National Bureau of Standards, 113 p (April 1957)
- 1100.\* Yamaguchi. Welfare ministry announces new radiation safety limit  
at one-tenth present international standard. Trans. from Asahi  
Press (Japan), 2 p (May 16, 1956)
1101. Minzner, R. A., W. S. Ripley. The ARDC model atmosphere, 1956,  
Air Force Cambridge Research Center, Report AF CRC TN-56-204  
(also AD 110233) (December 1956)







